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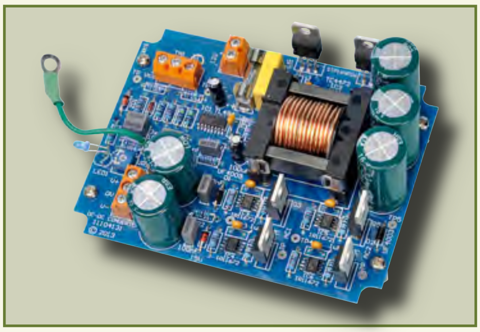

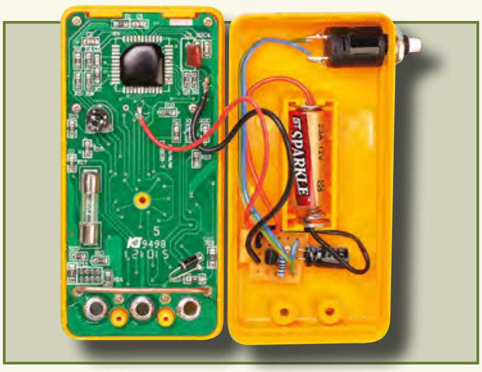

Our June 2014 issue will be published on Thursday 01 May 2014, see page 72 for details.

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Low cost PIC programmer board supporting a wide range of Microchip® PIC™ microcontrollers. Requires PC serial port. Windows interface supplied.
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The PIC Programmer & Experimenter Board with test buttons and LED indicators to carry out educational experiments, such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times for experimenting at will. Software to compile and program your source code is included.
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Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £10.95

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Kit Order Code: 3180KT - **£54.95**
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Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
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Additional DS1820 Sensors - **£4.95 each**

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Place next to a mobile phone (not included). Allows toggle or auto-timer control of 3A mains rated output relay from any location with GSM coverage.
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Most items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix).

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, Rings to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
Kit Order Code: 3140KT - **£79.95**
Assembled Order Code: AS3140 - **£94.95**

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
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Kit Order Code: 3153KT - **£37.95**
Assembled Order Code: AS3153 - **£49.95**

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone option and 2-wire serial interface for microcontroller or PC communication with simple command set. Suitable for common anode RGB LED strips, LEDs and incandescent bulbs. 56 x 39 x 20mm. 12A total max. Supply: 12Vdc.
Kit Order Code: 8191KT - **£29.95**
Assembled Order Code: AS8191 - **£39.95**

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

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4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application software.
Kit Order Code: 3190KT - **£84.95**
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Feature packed non-volatile 40 second multi-message sound recorder module using a high quality Winbond sound recorder IC. Standalone operation using just six onboard buttons or use onboard SPI interface. Record using built-in microphone or external line in. 8-24Vdc powered. Change a resistor for different recording duration/sound quality. Sampling frequency 4-12 kHz.
Kit Order Code: 3188KT - **£29.95**
Assembled Order Code: AS3188 - **£37.95**
120 second version also available

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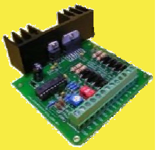
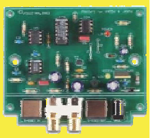


Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
Kit Order Code: 3187KT - **£39.95**
Assembled Order Code: AS3187 - **£49.95**

Video Signal Cleaner



Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
Kit Order Code: K8036KT - **£24.70**
Assembled Order Code: VM106 - **£36.53**

Most items are available in kit form (KT suffix) or assembled and ready for use (AS prefix).

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
Kit Order Code: 3067KT - **£19.95**
Assembled Order Code: AS3067 - **£27.95**

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
Kit Order Code: 3166v2KT - **£23.95**
Assembled Order Code: AS3166v2 - **£33.95**

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - **£17.95**
Assembled Order Code: AS3179 - **£24.95**

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
Kit Order Code: 3158KT - **£24.95**
Assembled Order Code: AS3158 - **£34.95**

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
Kit Order Code: 1074KT - **£15.95**
Assembled Order Code: AS1074 - **£23.95**

See www.quasarelectronics.com for lots more DC, AC and Stepper motor drivers

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Order Code: APS230 - ~~£374.95~~ £324.95

Handheld Personal Scope with USB

Designed by electronics enthusiasts for electronics enthusiasts! Powerful, compact and USB connectivity, this sums up the features of this oscilloscope. 40 MHz sampling rate, 12 MHz analog bandwith, 0.1 mV sensitivity, 5mV to 20V/div in 12 steps, 50ns to 1 hour/div time base in 34 steps, ultra fast full auto set up option, adjustable trigger level, X and Y position signal shift, DVM readout and more...
Order Code: HPS50 - ~~£289.96~~ £204.00

See website for more super deals!

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EVERYDAY PRACTICAL ELECTRONICS

We have a fantastic selection of articles and projects for you this month. It's all a great read, but three items especially caught my eye in this issue. Having just replaced what felt like the 100th halogen light bulb in my kitchen ceiling I was amused to read that the author of this issue's battery charger used redundant halogen transformers after opting to replace his halogen downlights with LED versions. If you need a good, simple battery charger then do check out this project.

PIC n' Mix

Next, Mike Hibbett's regular *PIC n' Mix* column has reached a particularly interesting point. He looks at 'C' programming and how to 'construct a microcontroller program, how to understand what gets created, and how to debug that application when it goes wrong.' For me, and many PIC-oriented readers, this is a significant moment, and I look forward to following the next few articles as Mike gets to grips with marrying 'C' and PIC projects. 'C' is a famously powerful but 'tricky' program to master, and it will be useful to have Mike's steady hand on the programming tiller.

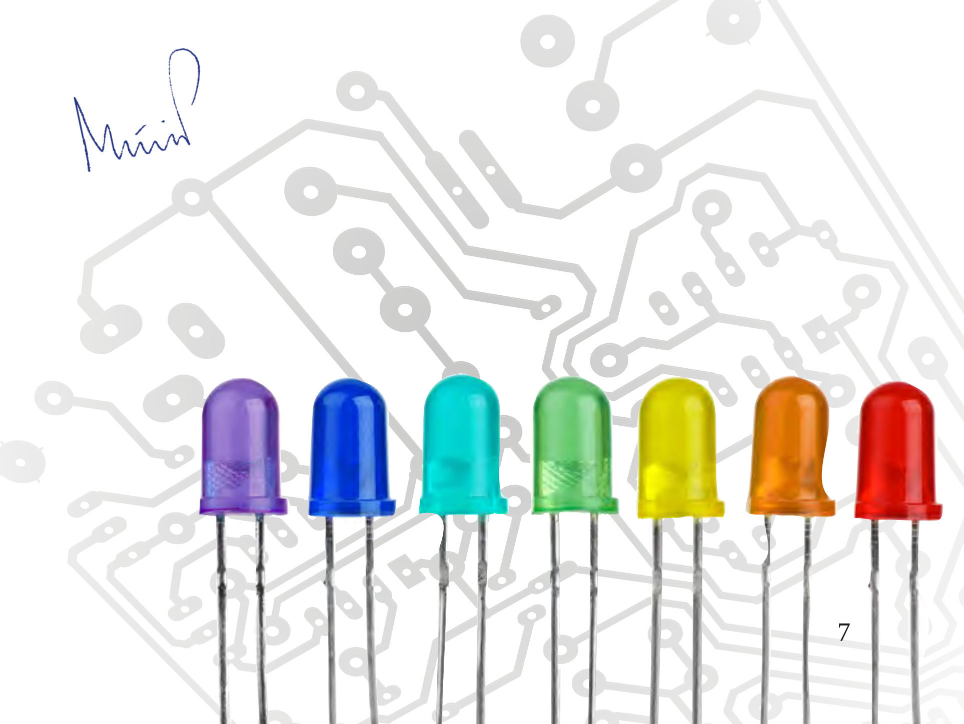
Teach-In 2014

My degree was in control engineering, which meant that when I worked in my first engineering job I tended to spend a fair amount of time interfacing circuits to actuators: motors, valves, heaters – assorted engineering bits and bobs that do something to the physical world. So I was very keen to read Mike and Richard Tooley's *Teach-In 2014* take on connecting the Raspberry Pi to stepping motors. They are an obvious and powerful combination, and I hope readers will find useful and entertaining ways to precisely control position and motion with their Pi/motor combos.

Teach-In 2014 code text downloads

A little late in the day I admit, but to avoid error-prone tedium by typing in the code for *Teach-In 2014* we are putting all the code on line for you to download. You can find the code files in the usual place, just go to the Library section of: **www.epemag.com**

I hope you enjoy reading this issue as much as we have enjoyed putting it together. As always, we welcome your emails, letters, *Chat Zone* questions, and feedback in general.



NEWS

A roundup of the latest Everyday News from the world of electronics

Microsoft's Ballmer at Oxford – report by Barry Fox

Steve Ballmer stepped down from his role of Microsoft CEO on 4 February this year – dogged by criticism of Windows 8, his pet new version of Windows that is so uncomfortably different from all previous versions that it deters people from replacing aging PCs.

Exactly one month later, and billed as the man who tripled Microsoft's revenue and doubled its profits, Steve Ballmer agreed to a question and answer session on 4 March at the Saïd Business School of the University of Oxford.

The modern Nelson Mandela Lecture Theatre of the Saïd (pronounced Saheed) was packed, mainly with MBA students, to hear Steve Ballmer answer questions for half an hour put by School Dean Professor Peter Tufano, and then for half an hour from the floor. Much of what Ballmer said, prompted by mainly business-oriented questions, was a stream of spontaneous wit, wisdom, thoughts and soundbites based on his career with Microsoft since 1980, when he joined as the company's first business manager, before becoming CEO in 2000.

Don't mention Win 8

But there was one very notable omission; Ballmer never once mentioned Windows 8 and its lack of popularity. No questioner asked directly about it, either. Ballmer behaved as if Windows 8 (and the 8.1 version released to try and stem criticism) had never existed. The closest he came to an admission of failure was to acknowledge that 'in the last ten years there are some things that did not go so well. We would have a stronger position in phones if I could re-do the last ten years'.

Dean Peter Tufano admitted he was nervous – once thanking 'Bill' (Gates) for his time. Ballmer tackled head-on the issue of his 'leadership style' as captured in the now famous YouTube clip of him at a Microsoft event careering round a stage proclaiming, 'I love this company' (**http://youtube/wvsboPUjrGc**).

'I am involving, energetic and passionate. I am a salesman by nature.

Steve Ballmer, former Microsoft CEO, taking questions at Oxford University's Saïd Business School

But I was painfully shy as a kid. Like a football manager, I like to bring groups with me. Microsoft is like a child to me. I love Microsoft like my children. My greatest joy will be to see it flourish with me gone. Of course, I can't say that all 100,000 of our people all say they love Microsoft.'

Best advice

'The best advice I ever got was from my father. If you are going to do a job, do a job. If you are not going to do a job, don't do it. He meant, be all in or all out. I am someone who is all in and stays in.

'The worst advice I ever got was not to drop out of Business School after a year and join Microsoft. That was cosmically the worst advice.'

What advice would Ballmer give new business ventures and web start-ups? 'Make mistakes, but fix the mistakes. If you have a failure you have got to fix it. If you don't succeed, don't give up and go home.

'To succeed you need adaptability, tenacity, capacity. Companies like Microsoft, Google, Facebook all took time to succeed. You don't just fall out of bed a success.

'You need to decide what success looks like. Sometimes having a lot of people sign up is a false metric. Take WhatsApp with 450 million users. Is it a fad? Probably not. It may generate revenue. There's no reason to doubt Zuckerberg's judgment.

'In the old days, if you wanted to know if someone was any good you asked how many thousands of lines of code they wrote in a month. It didn't matter that the lines were full of bugs.'

How did Ballmer handle projects that didn't much interest him? 'If you are running a company you can't not like anything. You are not allowed to. If you can't embrace something you will screw it up.

'In the early days I wrote a few simple programs in Basic, but I am not an engineer. I have never written a single line of production code. I never was an expert. But I engage by asking questions. You have to learn to ask the bright questions; to triangulate.'

More than a one-trick pony

Reminded by a BBC reporter that Microsoft had been early with touch screen devices, tablets and phones,

but 'caught napping' by competitors, Ballmer countered: 'Many companies are one-trick ponies. Don't laugh. It's good to have one trick. Most companies are zero-trick ponies. If you have one trick and get it right you can spin it and make it last and then go away. Microsoft has had at least two tricks, which were worth billions of dollars; one trick was the PC and Windows and Office; the other was getting microprocessors into the data centre.

'There was a little bit of magic, with PC hardware from IBM and our software.

'On mobile we got behind, but we didn't give up and go home. We came out with the Surface and phones and are buying Nokia.

'We are there, working hard. We do more tricks than most. I'd like to claim half credit for Xbox. So we have done two and half tricks. Apple has two tricks. Google has one.

What's the best thing about being immensely rich and powerful, he was asked. 'Fun – I can play any golf course I want. I'm a lousy golfer but I really love it. I've had a month to play and now I can re-boot. I have the luxury of being able to figure out what might be fun to do and make some difference in the world.'

What does Ballmer find disturbing about technology?' I don't worry at all. I view anything you worry about as more input into the technology cycle'

'If we were told that all the information about us is going to Google, or Facebook or Microsoft, and we can get $20 a year for it, my 22 year old son would probably say Yes. But I would say No. Which I guess tells that we all have a price.'

Be lucky

'Ideas matter. They do matter. The best ideas are something that people will want to use and buy. But you have also got to be lucky. Luck, and luck in connections and timing. If I hadn't known Bill Gates and Paul Allen when I did…'

'Bill laughed at the idea that 100 million computers would be sold. Don't underestimate the importance of luck'.

Energy-harvesting material

Researchers at the University of Bolton, led by Prof Elias Siores, are pioneering developments into 3D textile structures using piezoelectric energy-harvesting fibres.

The long-term results could lead to energy harnessing carpets or mobile devices, like phones and tablets, being charged on the move, according to research published by the Royal Society of Chemistry.

The research demonstrates the development of continuous piezoelectric yarns which show high flexibility and high mechanical strength. This has now made it possible for piezoelectric fibre to be woven into intricate and complex structures, such as 3D spacer textiles, opening a new horizon for commercial applications.

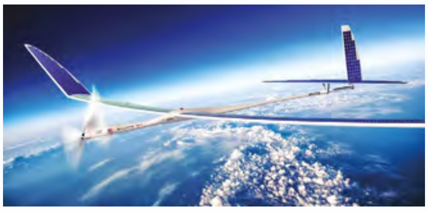
The University of Bolton's Knowledge Centre for Materials Chemistry post-doctoral research fellow, Dr Navneet Soin (co-author of the published research paper) said: 'We believe that this is just the first step in the creation of true wearable energy harvesting structures which do not look and feel any different from conventional fabrics, and yet provide the highest level of functionality.'

Flexible piezoelectric fibres can generate electricity by harnessing the energy created by an impact or movement, for example a footstep on a carpet, then converting that mechanical energy into electrical power.

Dr Soin added: 'The next step of the project is to focus on a couple of core applications and develop it from there. We envisage that with continued development in the area, we could be looking at actual commercial harvesters based on this technology in the next four to five years.'

Facebook web drones

Facebook has spent $60 million buying Titan Aerospace, which manufactures unmanned aircraft, or 'drones'. Titan's drones are solar-powered airplanes designed to fly as high as 65,000 feet and stay aloft for as long as five years. At that height, the vehicles are above conventional regulated air space and essentially function like cheap satellites. They could provide large areas with



wireless Internet, albeit slower than optical fibre land-based connections. For remote places like rural Africa or South America, they could provide breakthrough access.

Environmental impact of PV systems

For engineers and hobbyists interested in generating their own electricity, solar photovoltaic (PV) has long been an attractive option. This is especially true in Germany, where generous feed-in tariffs have encouraged widespread solar PV up take. A major argument for solar PV is environmental (for example, no CO_2 emissions) so to test this claim, the true impact of such systems has been studied by the German environmental institute 'bifa', which has just published an eco-efficiency analysis of photovoltaic systems.

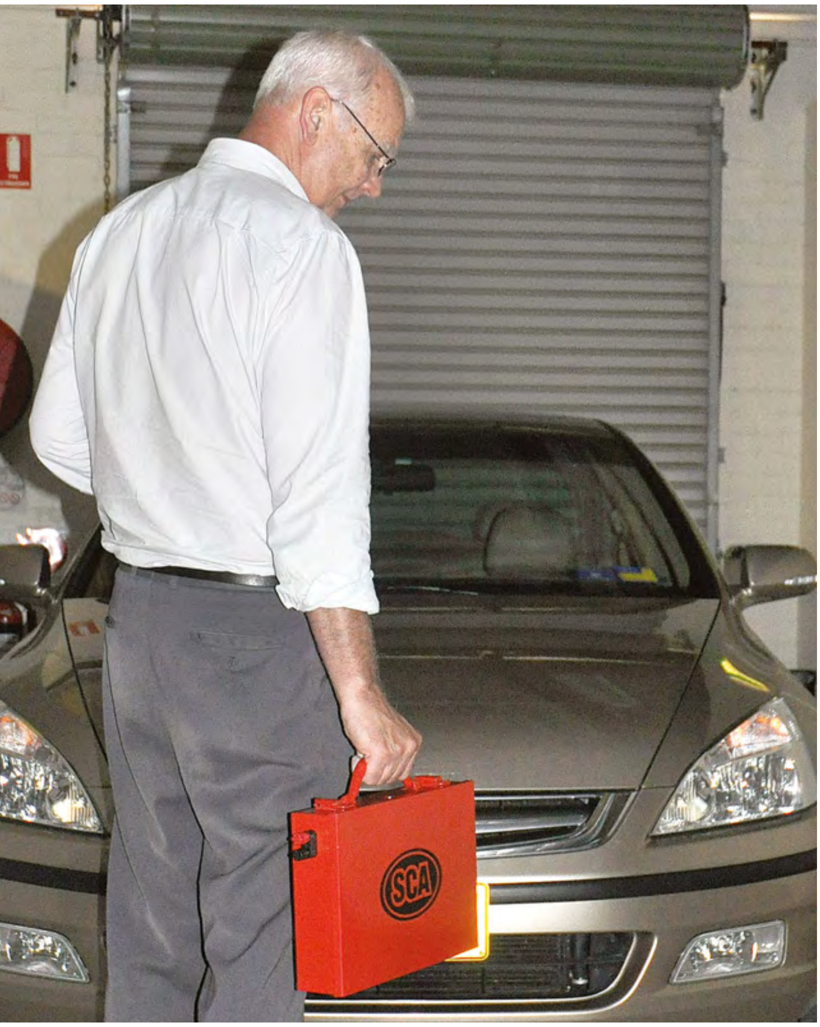
The study showed that taking into account the whole life cycle (manufacturing, operation and recycling) cadmium-telluride PV rooftop applications have the least ecological impact (in part, because they build on existing infrastructure).

Cognitive computing – the next disruptive technology

The next era of disruptive technology will come from cognitive computing, as the use of smart machines becomes more of a reality. This is according to a whitepaper – 'Cognitive computing' – produced by the British Computer Society (BCS).

Adam Thilthorpe, Director of Professionalism, BCS, said: 'Cognitive computing will have both positive and negative consequences, with machines able to perform tasks that were previously done by people. In recent years we've already seen the increased use of smart machines and over time these will be used to make health diagnoses, react to financial markets and aid performance in production processes. However, business relies on human judgement and conscience; this will be especially pertinent as machines become more intelligent and are able to process data independently.'

The whitepaper is the second in a four-part series which includes overviews of 'Ubiquitous computing (released in January 2014), Augmented reality, and 3D printing.



What do you do when you have stuff left over from another project? You think of uses for it, of course! Here we make some surplus halogen down-light transformers the heart of a simple car battery charger.

Rugged battery charger from Bits'n'Pieces

By Ross Tester

Earlier this year, we replaced some power-hungry 12V halogen down-lights in our office with much more efficient and brighter LED fittings. We're absolutely delighted with the result, but then we started thinking what we could do with the now-surplus 12VAC transformers and sundry light fittings/globes.

The light fittings and holders were consigned to the 'round file' – they were discoloured with age, the wiring was brittle and we certainly didn't want to put in any more halogen down-lights (that was the point of the exercise, after all). But at least the transformers were functional and it seemed such a shame to bin them. What on earth could we do with them?

We quickly came up with a number of ideas, and this is the first: a basic car battery charger that can put out a good 10A or so, with three of these transformers in parallel.

Commercial chargers with this rating are expensive, so if we could cobble up a cheap equivalent, so much the better.

We're assuming that the transformers you remove are iron-cored and not the so-called electronic type. 'Electronic' transformers cannot be used for our purpose.

Typically, the iron-cored transformers are labelled 4A (or close to it) and 11.4-11.6VAC. That means they're intended for 12V 50W halogen down-lights.

If you're removing them all from one area, the chances are they will be identical.

This is quite important as far as this project is concerned – you should not mix'n'match brands, otherwise one of them may tend to take the lion's share of the load.

If your transformers are identical in brand and style, the chances are also good that they were installed at the same time and are all part of the same batch, wound on the same machine, so the output voltages should be the same. You can check this out before use with a DMM if you wish – ours were within a couple of millivolts of each other.

We're using three transformers in parallel, which gives us a nominal output of about 12A (ie, 3 × 3.95A).

You won't quite get that much (we'll explain why shortly) but as we mentioned earlier, it should be good for around 10A. If you only need (say) 6A or so, or if you only have two identical transformers, go right ahead.

Using identical transformers in parallel is not too dissimilar to paralleling windings on the one transformer to give higher current.

For example, you might have a transformer which has two separate secondary windings rated at 6V, 1A – you can connect these (in the right phase) in series to give 12V @ 1A or in parallel to give 6V @ 2A. That is effectively what we are doing here.

Again, though, we must emphasise that they must be identical transformers – and definitely not electronic versions!

What else do you need?

Basically, all you need is a hefty bridge rectifier to convert the AC output of the transformers to unsmoothed DC, to charge a battery.

Naturally, you're also going to need hardware to safely connect the transformer primaries together (and thence to the mains) plus connections from the secondaries to the bridge rectifier and thence output cables for connection to the battery to be charged.

Add a case to put it all in and Bob's your uncle.

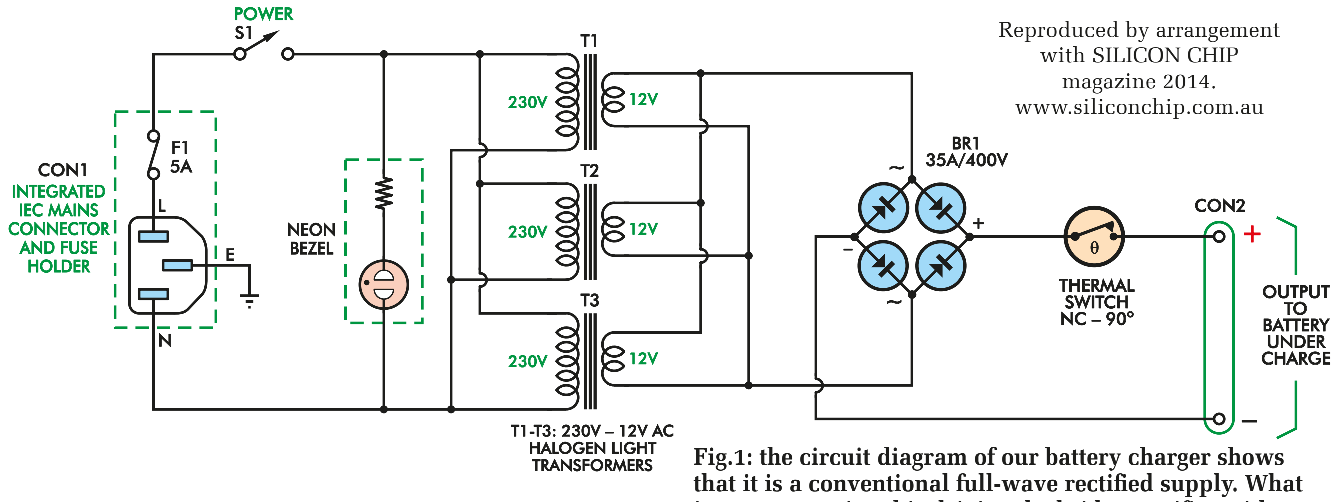
Well, nearly so. It will also need a mains cable, mains switch and fuse. We elected to use an IEC mains socket with integrated fuseholder – saves having a mains lead dangling out the back to get damaged and we also have plenty of IEC mains cords left over from other devices – you probably have a few as well.

You can get an IEC mains (male) socket with both integrated fuseholder AND mains switch, but we didn't want the mains switch on the back of the case, so elected to use a separate switch up front.

And because it's now getting rather difficult to buy a round-hole-mounting mains switch with an integrated neon indicator, we opted to add a separate neon bezel.

One of the three identical halogen down-light transformers we removed. They are each rated at 11.4V, 3.95A.

A 'cheap' auto storage box. Remove the seven plastic trays and presto! A case complete with handle!



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BITS'N'PIECES BATTERY CHARGER

Fig.1: the circuit diagram of our battery charger shows that it is a conventional full-wave rectified supply. What is not conventional is driving the bridge rectifier with three transformers in a parallel. It's not strictly-speaking according to the rule book – but we've proved that it works!

The case

This presented something of a problem. We wanted a metal case, preferably steel, to house the charger but once again, suitable cases are starting to become as rare as the proverbial.

And those that are available are worth a fortune – definitely not what we wanted for a 'surplus parts' project.

So instead of a purpose-made case, we purchased a steel storage box from a bargain, cheap-as-chips auto store for less than £20.

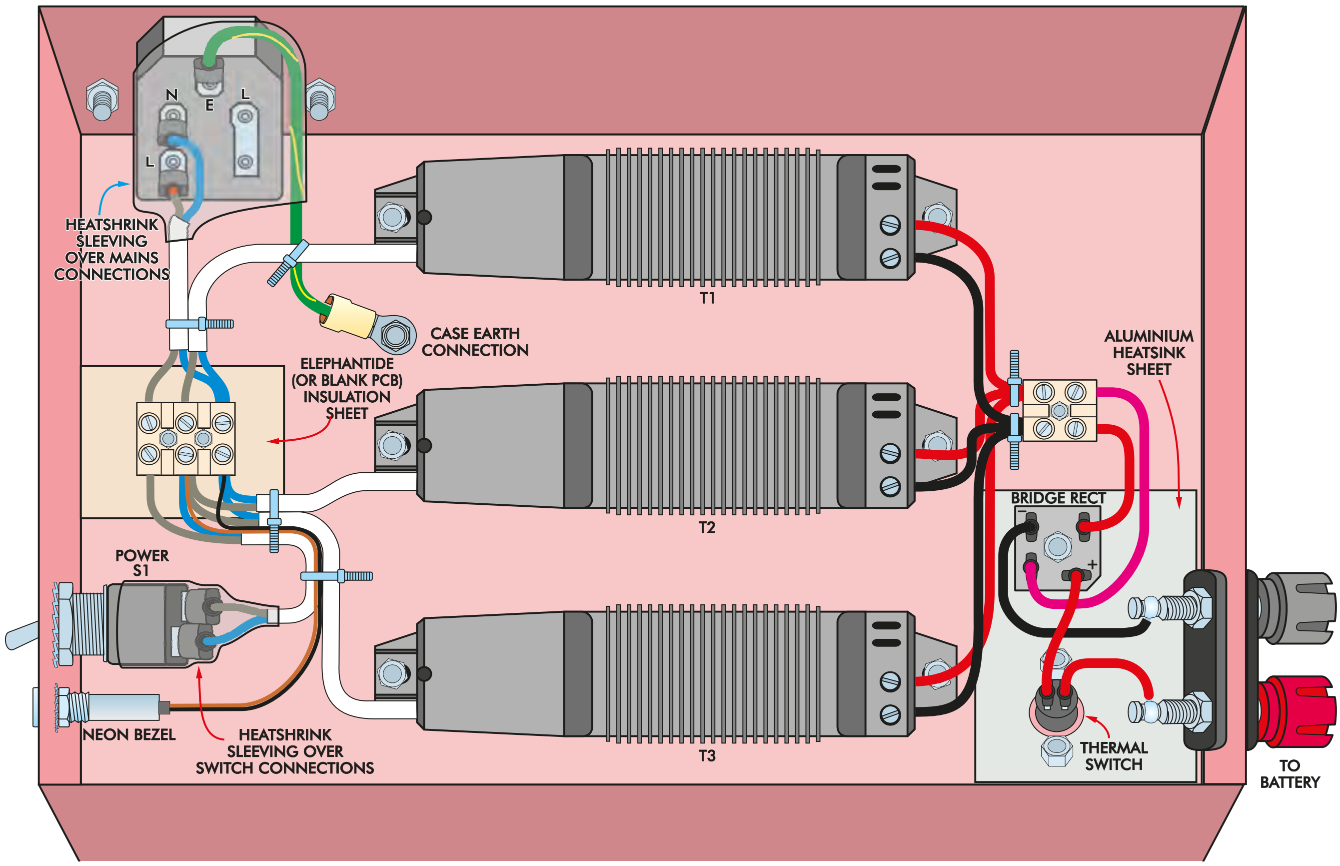
It's more than strong enough, about the right size and it has a couple of nice features such as a carry handle and provision for semi-permanent locking.

You might even find something suitable in a 99p or £1 store, and if you happen to have a suitable case on hand, then so much the better – and of course cheaper.

Output leads

We could have made up a set of charger leads from heavy-duty cable and large alligator clips, but 'why reinvent wheels?'. Cheap jumper leads already have the heavy-duty cable and large alligator clips – all we had to do was remove the clips from one end.

We've seen these before in bargain stores for less than £10 but of course, when we went to get them there



weren't any. You may even have a surplus set of leads that you can sacrifice for this project – they don't have to be super-high current leads.

If you have to buy some, get the cheapest you can find. Normally, we'd never recommend these – as jumper leads they make great shoelaces but for our purpose, they're more than adequate.

By the way, most jumper leads have rather extravagant claims for current rating – like 400A and so on. But if you look at the leads closely, you'll see that they are probably about 80% insulation and 20% (or less) wire.

Given the fact that they are intended for 12V (or perhaps 24V) usage, we wonder why they need insulation rated at, what, kilovolts and grossly exaggerated wire 'capacity'? Hmm!

What else did we use?

The main item is the rectifier – we used a metal 35A/400V bridge. We don't need either the 35A or 400V ratings but they give a nice margin for safety.

After this, a normally closed (NC) 90° thermal cutout to protect against shorting the output leads.

At the same time, we also grabbed a strip of 12-way ultra-large terminal strip and a couple of metres of 25A hookup wire.

Finally, we wanted some large output terminals – a polarised heavy-duty pair.

We could have saved this cost by bringing the charger leads out through a gland, but again, we didn't want to have leads permanently hanging from the case.

Apart from nuts and bolts to mount everything (see parts list), rubber feet, some heatshrink tubing and scraps of thick aluminium (to act as a heatsink) and PCB material (for an insulator), that was pretty much it.

The cost

OK, so if you have to buy everything (except the transformers!) it all adds up to £50-ish but we couldn't find a charger of this power for under £100 or thereabouts.

If you have a lot of what's needed in your junk box – and many hobbyists will – the cost will obviously come down significantly.

How it works

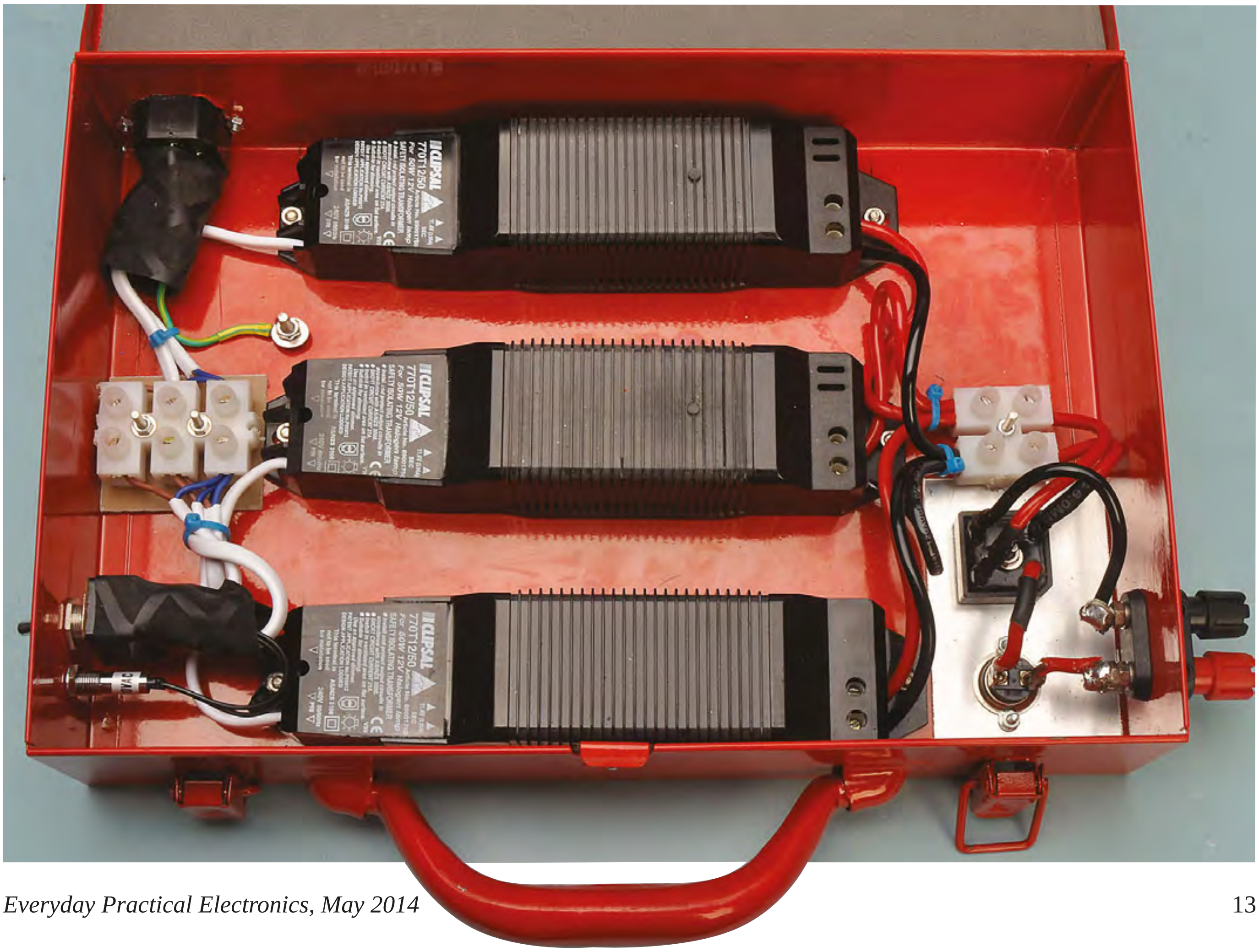
See the circuit of Fig.1. This one is definitely not rocket science! It's a typical full-wave rectified supply producing pulsating DC at the output.

What's not typical is that we've used three transformers, all wired in parallel, so all contribute their share of the nominal 12VAC @ 12A output to the bridge rectifier.

(We mentioned earlier that the transformers are labelled 11.4V, but this would be at the full 3.95A output. Unloaded or not fully loaded, the voltage is at least 12V, perhaps a bit more).

Once rectified, the pulsating DC voltage will be 12 × 1.4142 or 17V, less the voltage drop across the two diodes in the bridge rectifier conducting at the time (2 × 0.6 or 1.2V) leaves 15.8V. This is the peak voltage.

Because it is unsmoothed (ie, pulsating) DC, the voltage you read with



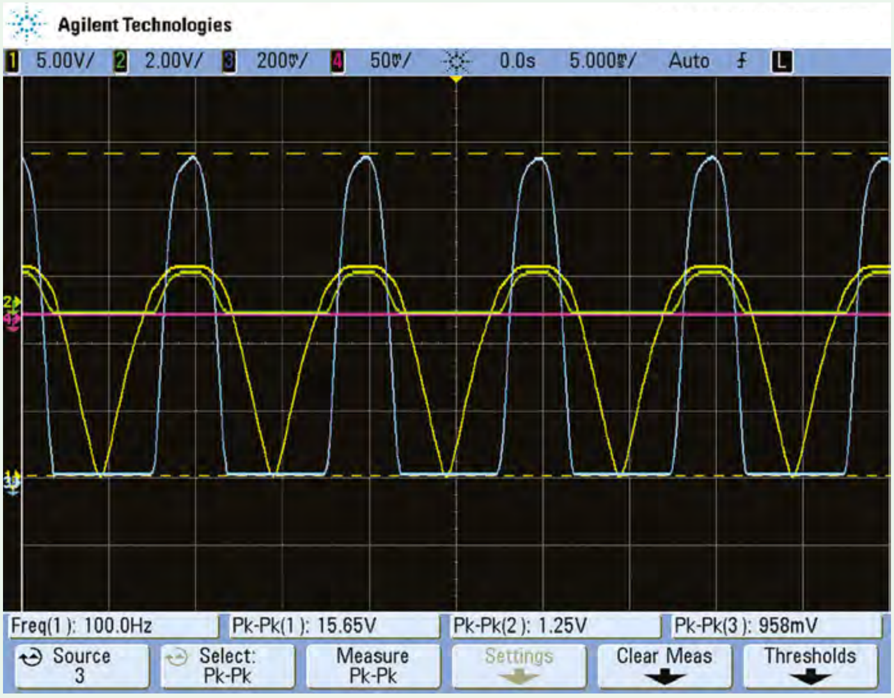
This set of four scope waveforms demonstrates the operation of this car battery charger.

The yellow trace shows the unsmoothed DC output of the battery charger with no battery connected but with a load of 1kΩ (to give a clean waveform).

The green trace shows the output of the battery charger when connected to a battery which is being charged at about 3A. The humps in the green waveform occur each time the battery gets a pulse of current (ie, 100 times a second or 100Hz).

The flat portions of the green trace represent the battery voltage at times between each current pulse while the pink trace (partly obscured by the green trace) represents the battery voltage when charger is turned off. Naturally, the average voltage when it is being charged will be slightly higher than when the charger is turned off. Hence the green trace is slightly above the pink trace.

The peaks of the yellow trace are slightly above the peaks of the green trace (battery voltage under charge). This is to be expected because the battery places a considerable load on the charger output.



The blue trace shows the amplitude of the 100Hz current pulses being fed to the battery. It represents the voltage across a 0.1Ω resistor in series with the negative lead from the battery charger and has a peak-to-peak voltage of 958mV (across 0.1Ω). This means that the current pulses are peaking at 9.58A; much higher than might be thought with an average current of about 3A.

Note that the maximum current delivered by the charger will depend on both the mains voltage at your location and the state of the battery being charged.

your multimeter will be less than this, actually peak ×0.707. So the output should measure around 15.8 × 0.707 or 11.17V. But aren't we trying to charge a 12V battery? How can we do this if the output voltage is less than the nominal battery voltage?

The reason is that current flows into the battery whenever the peak voltage exceeds the battery's nominal voltage. Remember a moment ago we said that the peak voltage was about 15.8V?. So when the charger voltage rises above 12V (or whatever the battery voltage is at the time) current will flow into the battery, charging it.

And this happens 100 times every second as the pulsating DC voltage starts at zero, rises up to 15.8V then falls to zero again. See the scope grab of the waveform above.

The twin output terminals (binding posts) we used – these have large holes which easily fit the jumper lead cables. Some binding posts can be a real pain to connect to!

We chose an IEC socket with integral fuseholder (at the bottom) – it means the fuse is before the mains switch, but this isn't a great problem.

The latches on our case have a screw hole right through them, which means you can semi-permanently lock the case. (See screw and nut at bottom of latch). That's important if there are young hands around.

Parts list – Rugged Battery Charger

3 (or 1 or 2 – see text) 230V to '12V' @ ~4A downlight transformers, same brand and type (**not electronic type**)
1 suitable steel or aluminium case, approx. 330mm × 225mm × 68mm
1 IEC male chassis connector with integral fuse holder and 5A fuse
1 SPST mains switch
1 Neon bezel (230V)
1 BR354 (or similar) 35A/400V bridge rectifier
1 90°C thermal switch, normally closed
2 large red and black terminals (binding posts)
1 12-way large terminal block
1 earth lug crimp terminal
1m 25A auto cable – red and black
1m twin-core mains cable
1 set economy jumper leads
Heatshrink to cover mains socket and switch, all exposed terminals
5 M3 × 10mm screws with nuts and washers
3 M3 × 20mm screws with nuts and washers
8 M4 × 10mm screws with nuts and washers
1 M3 × 30mm screw with nut and washer
4 rubber feet, self-adhesive
1 aluminium offcut for heatsink, roughly 100 x 60mm
1 blank PCB or plastic offcut for mains terminal block insulator, roughly 50mm × 50mm
Small cable ties

How much current?

We mentioned earlier that you wouldn't expect to get the full 12A from three 4A transformers. There are losses in the system – for example, the voltage losses in the rectifier and also due to the resistance of the wiring and leads.

But we'd be surprised if you didn't get at least 10A peak into a 'flat' battery as ours did. This reduces, of course, as the battery charges.

The one big disadvantage of a simple battery charger like this is that it will continue to try to 'charge' the battery, even though the battery is nominally 'charged'.

So beware of this – if the battery fluid starts to bubble (gas), turn off the charger and disconnect it (not the other way around – that bubbling is hydrogen gas and you really don't want to have any sparks around that!).

Construction

Layout within the case is not critical, the main thing to remember is that this is a mains device – care must be taken with the mains wiring and the output wiring must be kept completely separated from the mains, with no possibility of connection should a wire work its way loose.

One advantage of the transformers we used is that they have nice, big holes for cable connection – even 25A auto cable fits easily.

We marked all hole positions before drilling any. That way you can easily move something if necessary!

Start by placing the transformers in the case. If you're using three, as we did, it makes sense to locate one right in the middle (ie, on the centreline) and the others lined up, about 10mm in from the edge of the case.

When you're happy with their positions, mark their screw hole positions with a fine felt pen.

The two lengths of terminal strip (one 3-way, one 2-way) also sit on the centreline. The 3-way length, the one that connects mains power, has two screws holding it in while the 2-way obviously can have only one screw.

At the 'mains' end, you'll need to mark a hole position for the earth screw. We positioned the mains switch and neon on the end of the case, equal distance from top and bottom. The bezel (7mm hole) is 25mm in from the front and the mains switch (12mm hole) another 20mm further in.

The only other hole in this end of the case is the cutout on the rear for the fused IEC socket. Mark its position and cutout carefully – for our case there wasn't a great deal of 'meat' on the edges of the socket. The cutout can be made by either drilling a series of small holes and finishing off with a file, or using a nibbler. Note that there are two chamfered corners on the bottom of the cutout.

At the opposite (output) end in the bottom of the case there are holes required for the 2-way terminal strip mentioned above and the bridge rectifier and thermal cutout. We mounted the two latter components on a small piece of thick aluminium to act as a heatsink, with screws going through both the case and heatsink. We worked out the positions of both components on the heatsink then used that as a template to drill the holes through the case.

The pair of output binding posts needs careful drilling to ensure it fits and sits correctly – it has two 10mm holes 19mm apart. Again, this socket was mounted at the midline of the side of the case, the first hole 25mm from the front edge and the second (obviously!) 19mm further in.

We used M4 screws for the transformers, earthing point and bridge rectifier; M3 for the rest. You will need to remove paint around the earthing point so that the screw is guaranteed to contact bare metal. This screw needs to have, from the case up, a star washer, nut, crimped earth wire lug, shakeproof washer and finally another nut to ensure the earth wire is held securely in place.

Because there are screwheads emerging from the bottom of the case, it makes sense to place some rubber feet on the underside – because the chances are someone will 'rest' it on a car bonnet. Self-adhesive feet are easiest – you don't need to drill any holes.

Connecting it up

Once all the holes are drilled/cut, it's quite a simple matter to connect it all together using our photos and diagrams as a guide.

Ideally, we would have used spade (quick-connect) connectors to attach to the various terminals, but there are two problems here – the different sizes of lugs (I think there are five!) and second, the thickness of the wire on the secondary side makes getting the connectors on and crimped a bit of a chore. OK, there was a third problem – I forgot to buy any!

So I elected to solder all connections. Just make sure before you solder that the wires make a good mechanical connection (ie, they won't pop off even without solder).

Pre-tinning any connectors also makes sense because it's sometimes difficult to solder thick wire – it really sucks the heat away from the iron. With pre-tinning you have a much better chance for a really good solder joint.

The connections between the transformers and bridge rate special mention. We already said that we obtained some thick (ie, high current) wire for these but we haven't mentioned they should all be cut to *exactly* the same length. This is to ensure, as far as possible, that the load is shared between the transformers – even a few milliohms of difference could matter.

We used red and black wire simply because we had some and that made the phasing of the transformers easy – it's essential that the three (or even two) transformer outputs are connected in phase, otherwise they will see a short circuit in each other.

Ideally, you should check that the outputs are in phase by comparing the waveforms on a 'scope. But if you don't have one, don't worry too much – again, with three identical transformers you'd expect the terminals to be connected the same way.

Now you'll find out why we used an ultra-large terminal strip – you need to connect the three wires together and anything smaller simply won't have room to fit them in. As it is, they're a tight fit – but they do. Fit, that is!

We've only run one length of wire from the terminal strip to each of the bridge terminals – we would have liked to use a larger cable but didn't have any.

Again, wrap the bare wire around the bridge terminals before soldering – that's after you take note which terminals are which. One of the AC (input) terminals is always identified, as is the + terminal. The diagonally opposite terminals are the other AC input and the – terminal, respectively.

A thick black wire connects directly from the – bridge terminal to the black output terminal, while a thick red wire connects from the bridge + terminal to the thermal cutout, with the same from the thermal cutout to the red output terminal.

We covered all exposed terminals (ie, on the IEC socket and the switch) with heatshrink tubing and shrunk it to fit when finished. The same treatment was given to all soldered connections on the output side – the bridge rectifier, the thermal cutout and the output terminals.

All closed up and ready to go. You've even got a handy carry handle to carry your charger to where it's needed!

And finally, we used a few small cable ties to bundle the wires together.

Is it finished?

Once you've checked all your wiring – and especially checked that no strands of wire poke out from your terminal strips – you can test that it works.

Don't connect any output leads yet, but connect a, say, 1kΩ resistor (any wattage) across the output terminals to give the rectifier a small load (that's all it needs at the moment).

Plug in power and turn it on. The neon should glow, telling you that so far all is well.

Measure the AC voltage at the terminal strip where the three transformer leads join. It should read just on or over 12VAC. Measure the DC voltage at the output terminals and it should be something similar – perhaps 11.5V (again, if you're wondering why, read the explanation earlier on).

Turn it off, remove the resistor and connect your output leads. While monitoring a 12V car battery voltage, connect the clips to the battery and turn it on again.

Unless your battery is fully charged, you should find the voltage rises a little and keeps rising. You should also find that the voltage is somewhat higher than your previous check without the output leads because the battery acts like a giant capacitor or reservoir, smoothing out the peaks of the waveform and thus increasing the average voltage value.

Leave the charger on for, say, half an hour or so and check the temperature of the transformers. They will probably be quite warm but not excessively hot (they get pretty hot to the touch when operating in your ceiling!). Likewise the bridge rectifier. If that gets too hot, the thermal cutout will trip and cut power to the output.

Closing 'er up

If you're happy that everything works as it should, close the case up and snap the locks closed.

If you look closely at the bottom of the locks, you'll note that there is provision for inserting a 3mm screw (with nut), about 30mm long, through the whole thing, which stops the locks being opened. We'd be inclined to do this – despite covering all the bitey bits with heatshrink, you don't want anyone's fingers (especially little ones) inside the case.

What's the charging current?

Next month, we'll show you how to add both a digital ammeter and a digital voltmeter so you know exactly what's going on. Having set out to produce a low-cost, surplus parts battery charger this could be regarded as 'gilding the lily' somewhat!

They do add to the cost of the project but also add significantly to the value and we think both are worthwhile additions (of course, you could choose to add only one meter instead of two – and/or leave it as is).

An alternative would be to use a couple of cheapo digital multimeters. Some are available for just £5 each – even cheaper than panel meters!

High-Q re-juicing and joined-up objects

TechnoTalk

Mark Nelson

Prospects for cordless charging and the emergence of the 'Internet of Things' are on the menu for this month's commentary – Mark Nelson reports

PROBABLY the only thing users would admit to hating about their smartphone is the short battery life and the need to 're-juice' their handset daily. Consumers loathe the tangled cords and cumbersome adapters that feed their portable electronic devices. Plugging into a charger is not only a pain in the neck, but potentially shortens the smartphone's life by disturbing the soldered joints on the power connector. Wirefree power transfer is the obvious solution, and as American market research company IHS states, is set to worm its way into not just mobile phones but also portable media players, digital still cameras and mobile PCs.

Modest market

Currently, market penetration is modest, mainly because the interface is not yet standardised, but this could change soon, with 700 million systems forecast to employ wirefree charging by 2018. According to tech analyst IHS, the mobile phone and tablet markets will kick-start volume adoption of the technique. Henry Samueli, chairman and chief technical officer of solutions for communications semiconductor company Broadcom, argues: 'Wireless charging standards have to converge and I think this year they will figure out this market is not taking off until they get together. It's about much more than a smartphone market. The main driver is the Internet of Things.'

We'll come back to the 'Internet of Things' in a moment, but first let's examine wirefree charging technologies. According to Samueli, the end goal is convergence around a single industry standard 'so you can charge any phone on any charging plate. Nothing takes off in a big way until it becomes an industry standard that guarantees interoperability of multiple products from different vendors. We will see more and more wireless charging solutions come on the market as the standards crystalise in 2014.'

Drop-and-go

Up to now, cordless charging has relied on electromagnetic induction, a technique working just like the primary and secondary windings in a transformer. The only difference is that the two coils are separated physically, with the primary in the charger and the secondary in your smartphone or other user device, which must be aligned accurately alongside the charger to work. Chargers are device-specific, meaning that each phone needs its own charger that refreshes only one gadget at a time.

The new generation of wirefree chargers employs 'resonant transfer technology', in which a coil is made to 'ring' or 'vibrate' at a specific frequency using an oscillating current to generate an oscillating magnetic field. The coil's high resonance factor (you may know this as Q) means that energy placed in the coil dies away relatively slowly over very many cycles. When a second high-Q coil tuned to the same frequency is brought nearby, it can capture most of the energy before it all dissipates. The concept builds on Nikola Tesla's pioneering ideas and experiments over a century ago. It is claimed that coil-to-coil efficiencies of 90 per cent or more are achievable in these applications, with end-to-end efficiencies of over 80 per cent.

Resonant charging has three key advantages over the inductive method:

- Superior charging range, allowing for a true drop-and-go charging experience, through almost any surface, unaffected by objects such as books and clothing
- A single charging pad can charge up to eight devices with different power requirements at the same time, such as smartphones, tablets, laptops and Bluetooth headsets
- No conflict with metallic objects such as keys and coins, making it an ideal choice for automotive, retail, and kitchen applications.

Furniture manufacturers could embed charging pads into conference room tables or your bedside drawers. Users would only have to place their gadgets on the table surface for it to start charging. Time will tell if this will become reality, but a lot of smart money is banking on this.

Internet of Things

I promised to explain the Internet of Things (alias the 'Internet of Everything'). You have probably heard the expression used a number of times and meant to look up what it actually meant. Certainly I did – and now I can share the answer. Actually it's not a new idea and dates back to 1991 at least. The actual term was first coined in 1999 and relates to the concept in which all manner of items (gadgets, gizmos, devices and other things) are integrated into an information network and communicate with one another seamlessly. Physical objects can become active participants in business or domestic processes, interacting with other 'smart objects' over the Internet to query and change their state or share any information associated with them.

From milk to MOTs

Originally, people discussed refrigerators that called up online grocery stores when you were running out of milk and cheese and household thermostats that shut the curtains and put another log on the fire when the temperature fell outdoors. Nowadays, car manufacturers are talking about onboard intelligence that sends you a text when the MoT test is due and slows the car down to avoid infringing the speed limit. The economic advantages are potentially vast: homes and businesses might never run out of vital commodities, shops would never be 'out of stock', traffic congestion could be reduced and the generation of waste products could be reduced.

Future growth

The number of devices connected to this Internet of Things by 2020 is forecast to be 26 billion by analyst Gartner and 30 billion by ABI Research. The Smart Data Collective tempers these ambitious forecasts with a note of caution, however. 'Unlike previous waves of computing, the Internet of Things is going to take many years to reach its full potential,' argues one of their contributors. 'We still drive on roads, rely on electricity and utilise hospitals that are based on technology that really hasn't benefited from the same leap in productivity that has supercharged the back office.'

As always, time will tell!

The CLASSiC-D ±35V DC-DC Converter

Delivers up to ±35V and 125W from a 12V battery with high efficiency

By JOHN CLARKE

This compact ***DC-DC Converter*** was designed to mate with our ***CLASSiC-D Amplifier*** (published in November and December 2013). It presents an efficient way to run the ***CLASSiC-D Amplifier*** module from a battery to make it a compact powerhouse. Of course, it can also be teamed up with other amplifier modules too, if you already have them on hand, and its output voltage can be adjusted over a small range.

THIS DC-DC CONVERTER is designed to deliver ±35V DC supply rails from a 12V DC input. At that setting, it will enable the *CLASSiC-D Amplifier* to deliver some 100W into 4Ω and 60W into 8Ω. This is certainly less than the *CLASSiC-D's* maximum output of 250W when powered from ±55V supply rails, but we have chosen this setting as a good compromise between power output and battery life.

And while the *DC-DC Converter* can be used with other power amplifier modules which have a similar supply rail requirement, they will not be as efficient as the *CLASSiC-D* module and therefore will not give you as much audio output for a given battery current.

The *Converter* is housed in a rugged diecast box measuring just 119mm ×

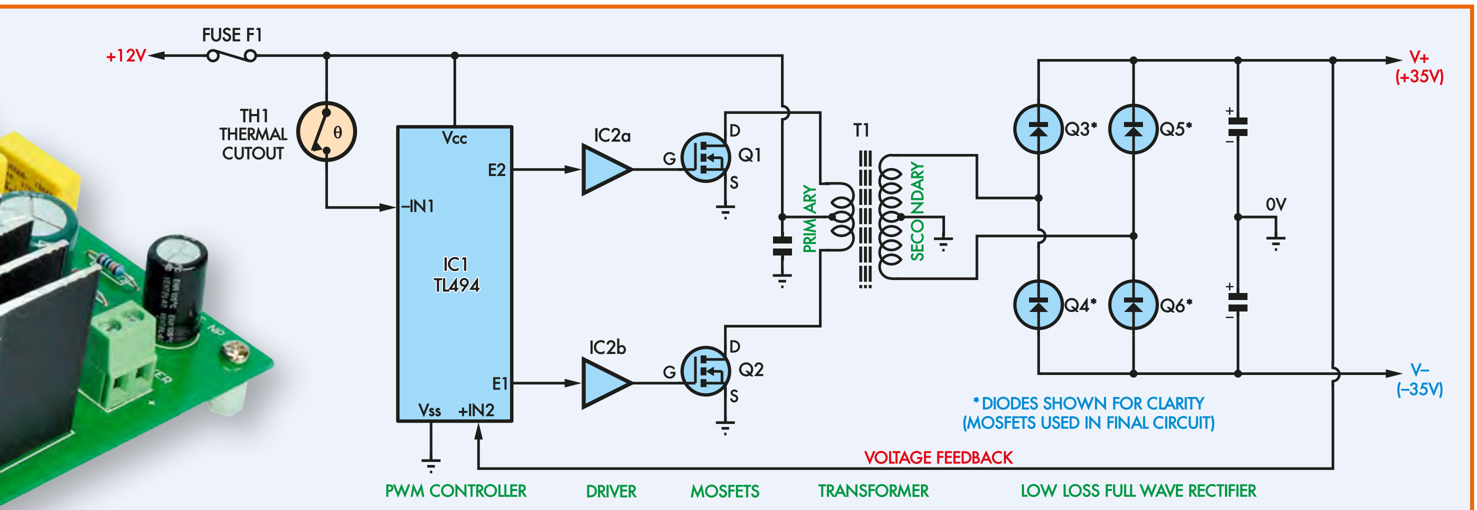


Fig.1: a simplified diagram of the *DC-DC Converter*. It uses a TL494 switch-mode PWM controller (IC1) to drive MOSFETs Q1 and Q2 in anti-phase and these drive transformer T1 at about 25kHz. The transformer secondary then drives a rectifier stage to derive ±35V rails.

94mm × 57mm. Just add the CLASSiC-D Amplifier module and a 12V SLA battery and you have the basis for a powerful portable PA amplifier or a really punchy busking amplifier, with good battery life.

Main Features and Specifications

Features

- Compact housing
- Efficient rectifier circuitry
- Thermal shutdown
- Fuse protection
- Power indication

Specifications

Power supply: 11.5-14.4V using a 12V battery (or 24V with modifications)

Power rating: 50W continuous, 125W peak (enables the CLASSiC-D Amplifier to deliver up to 100W into 4Ω on normal program material)

Standby current: 130mA at 12.6V

Standby Current with CLASSiC-D Amplifier connected: 220mA in protect mode; 490mA in run mode with no signal

DC supply ripple at 60W load: less than 2V

DC-DC converter basics

The *DC-DC Converter* works by alternately switching 12V to each half of a centre-tapped transformer primary winding. The resulting AC waveform is then stepped up in the transformer's centre-tapped secondary, rectified and filtered to provide the plus and minus supply rails.

Fig.1 shows the basic schematic of the *DC-DC Converter*. It operates at a switching frequency of about 25kHz and uses a high-frequency ferrite transformer. MOSFET Q1 drives the top half of the step-up transformer, while Q2 drives the bottom half. The secondary winding's centre-tapped output is fed to a bridge rectifier and filter capacitor stages to develop the plus and minus DC output rails.

The MOSFETs are driven via separate drivers, IC2a and IC2b, by a TL494 switchmode chip (IC1) which has feedback to keep the positive DC voltage to a set value (ie, 35V). This feedback controls the width of the pulses applied to the gates of the MOSFETs. If the voltage rises above the set value, the width of the gate pulses is reduced, and vice versa. The two MOSFETs are switched in anti-phase, so that when one half of the winding is conducting, the other is off.

Fig.1 shows the rectifiers as diodes, but in reality they are MOSFETs, hence the Q numbers (eg, Q3). The reason for using MOSFETs instead of fast recovery diodes is that they are far more efficient, since they have less forward voltage drop than diodes.

The circuit also incorporates a low voltage cut-out and over-temperature protection. If the battery voltage drops below 11.5V, the converter switches itself off. This is essential if you are powering the converter from a 12V SLA battery. If these batteries are allowed to discharge much below 11.5V, they will be rendered useless. That can be expensive and frustrating!

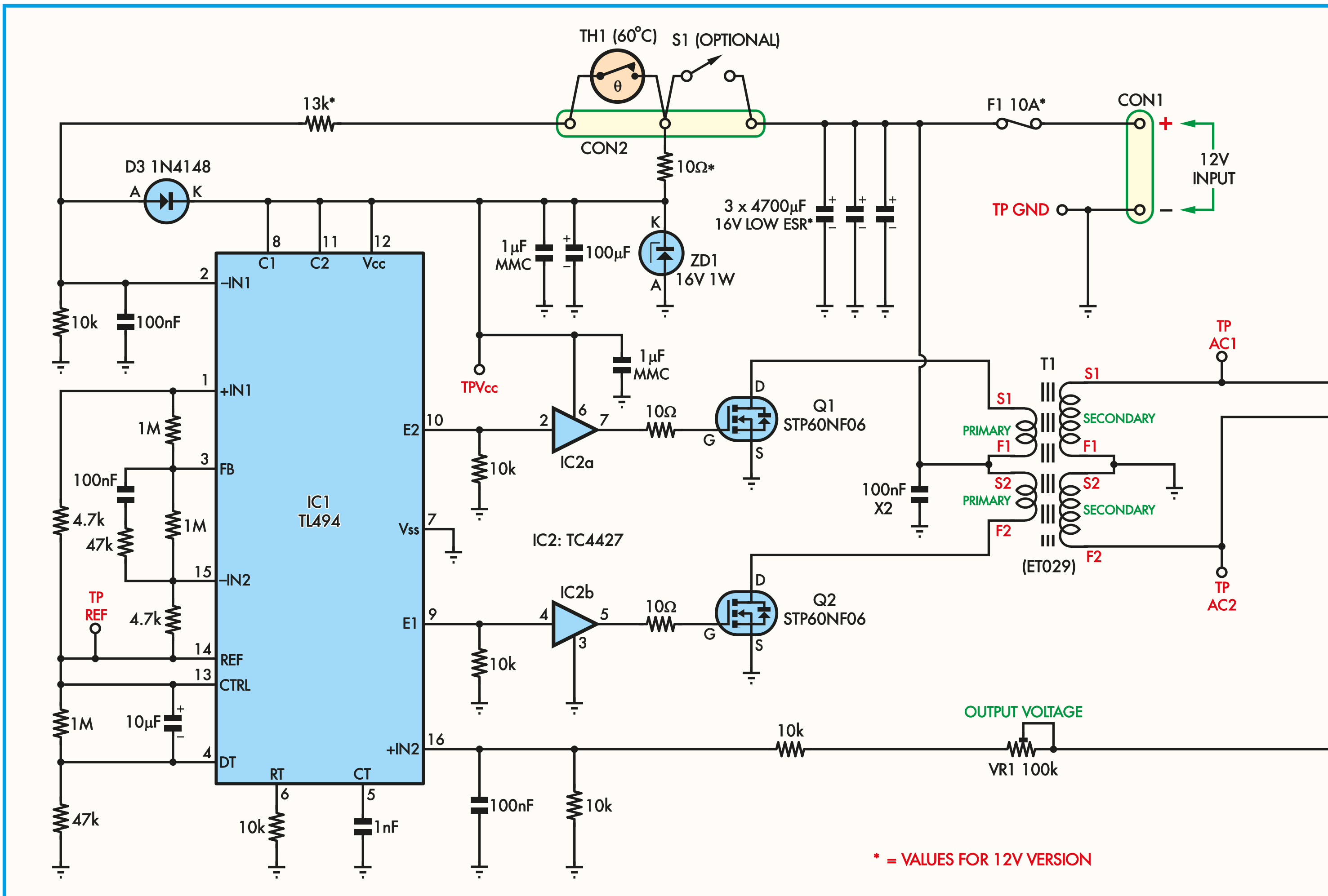
Over-temperature protection is provided by a thermal cut-out attached to the inside of the diecast case. If the case temperature exceeds 60°C, the thermal cut-out opens and the converter shuts down. When it cools sufficiently, normal operation resumes, with no harm done.

Circuit details

Fig.2 shows the full circuit of the *CLASSiC-D DC-DC Converter*, while Fig.3 shows the internal circuitry of the TL494. It is a fixed-frequency pulse-width modulation (PWM) controller containing a sawtooth oscillator, two error amplifiers and a PWM comparator. It also includes a deadtime control comparator, a 5V reference and output control options for push-pull or single-ended operation.

The PWM comparator generates the variable width output pulses by comparing the sawtooth oscillator waveform against the outputs of the two error amplifiers. The error amplifier with the highest output voltage sets the pulse width.

Pin 13 selects single-ended output or push-pull operation. In our design, push-pull operation is selected and



CLASSIC-D DC-DC CONVERTER

Fig.2: the full circuit of the *CLASSiC-D DC-DC Converter*. It uses MOSFETs Q3-Q5 to rectify the AC from transformer T1's secondary and these are controlled by four IR11672 secondary-side driver (SSD) ICs (IC3-IC6). Each SSD monitors the voltage across its MOSFET to determine when to switch the MOSFET on or off via the V_{GATE} output.

the outputs appear at the transistor emitters, with the collectors tied to the positive supply.

Dead-time comparator

The dead-time comparator ensures that there is a brief delay between one output going high and the other going low. This means that the outputs at pins 9 and 10 are both low for a short time at the transition points.

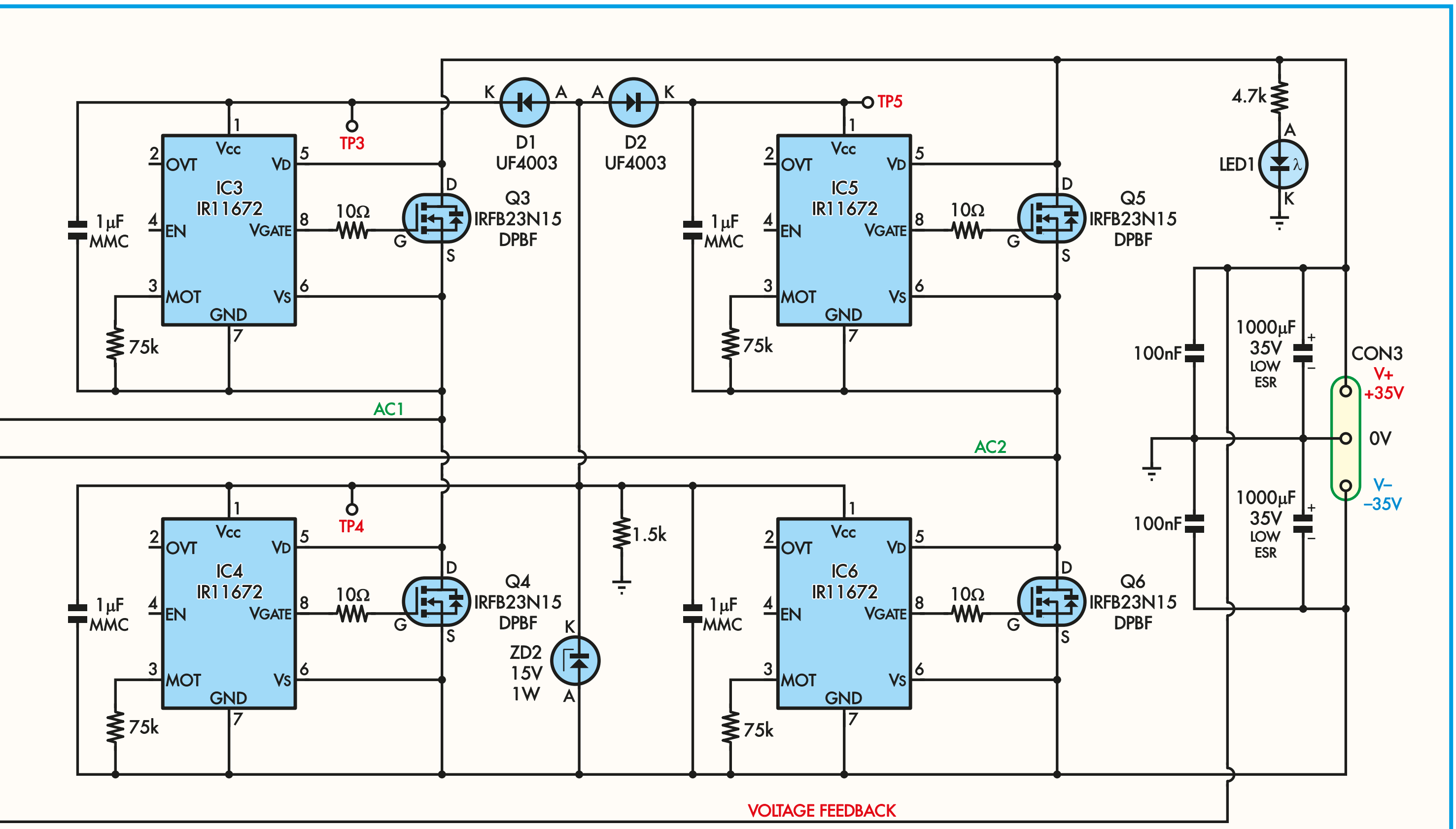
This dead-time period is essential, since without it, the MOSFET driving one half of the transformer would still be switching off while the other MOSFET would be switching on. This would destroy both MOSFETs as they would effectively create a short circuit across the 12V supply.

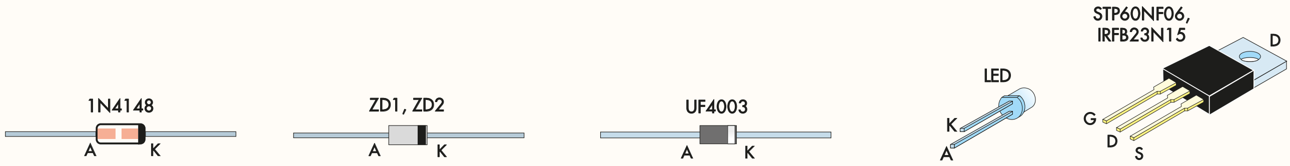
One of the error amplifiers in IC1 is used to provide the under-voltage protection. Pin 2 monitors the +12V rail via a voltage divider consisting of 10kΩ and 13kΩ resistors. Non-inverting input pin 1 connects to IC1's internal 5V reference at pin 14 via a 4.7kΩ resistor. When the voltage at pin 2 drops below 5V (ie, when the battery voltage drops below 11.5V), the output of the error amplifier goes high and the PWM outputs at pins 9 and 10 go low, thus shutting the circuit down. The 1MΩ resistor between pins 1 and 3 provides a small amount of hysteresis so that the output of the converter does not rapidly switch on and off if the battery is close to the 11.5V threshold.

The over-temperature protection operates with a 60°C thermal cut-out (TH1) connected in series between the voltage divider on pin 2 and the positive supply rail. If the case temperature reaches 60°C, TH1 opens and the circuit shuts down by turning the PWM off.

The second error amplifier in IC1 is used to control the output voltage of the DC-DC Converter. This amplifier has its inputs at pins 15 and 16. The feedback voltage is derived from the positive side of the bridge rectifier and is attenuated using a voltage divider consisting of VR1, a series 10kΩ resistor plus a 10kΩ resistor to ground. The resulting voltage is then fed to pin 16 of IC1 and compared to the internal 5V reference which is applied to pin 15 via a 4.7kΩ resistor.

Normally, the attenuated feedback voltage should be close to 5V. Should this voltage rise (due to an increase in the output voltage), the output of the error amplifier also rises and this reduces the output pulse width. Conversely, if the output falls, the error amplifier





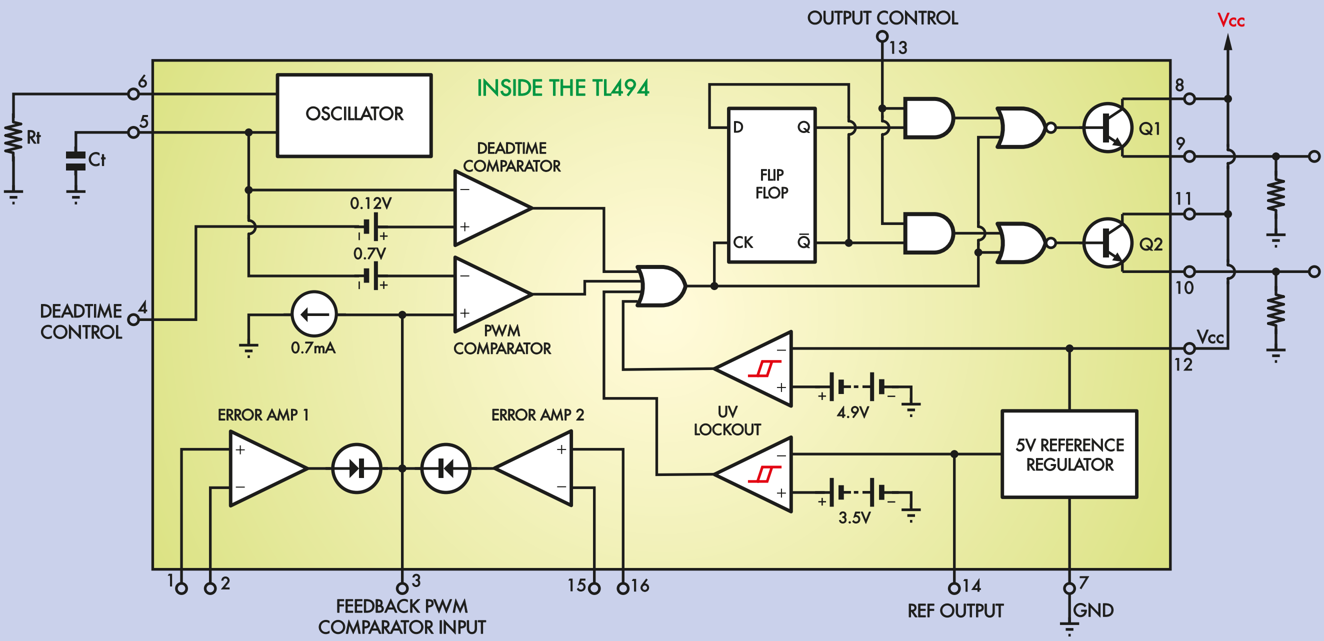


Fig.3: the internal circuit of the TL494 switch-mode pulse-width modulation (PWM) controller. It is a fixed-frequency PWM controller containing a sawtooth oscillator, two error amplifiers and a PWM comparator. It also includes a dead-time control comparator, a 5V reference and output control options for push-pull or single-ended operation.

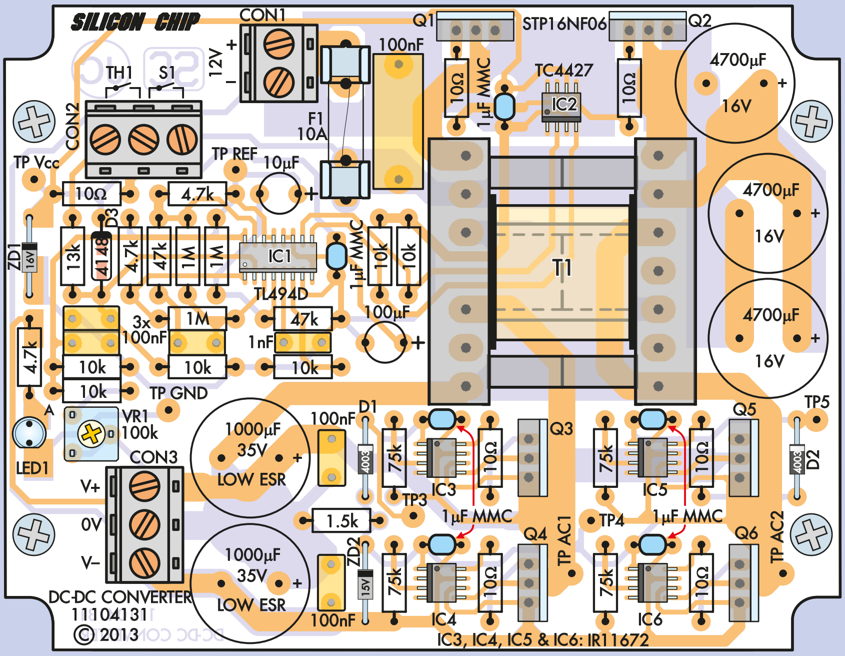


Fig.4: install the parts on the PCB as shown on this layout diagram, starting with the SMD ICs (IC1-IC6). Be sure to orient the ICs, MOSFETs, diodes, Zener diodes and electrolytic capacitors correctly

output also falls and the pulse width increases.

The gain of the error amplifier at low frequencies is set by the 1MΩ feedback resistor between pins 3 and 15 and by the 4.7kΩ resistor to pin 14 (V_{REF}). These set the gain to about 213. At higher frequencies, the gain is set to about 9.5 by virtue of the 47kΩ resistor and 100nF capacitor in series across the 1MΩ resistor. This reduction in gain at higher frequencies prevents the amplifier from responding to hash on the supply rails and ensures stability.

The 10kΩ resistor and 1nF capacitor at pins 6 and 5 respectively set the internal oscillator to about 50kHz. An internal flipflop divides this by two to give the complementary 25kHz output signals at pins 9 and 10. Note that while most of the inverter circuitry could run at much higher speed, 'skin effect' in the windings of the ferrite-cored inverter transformer sets the practical limit for switching the MOSFETs to around 25kHz.

Pin 4 of IC1 is the dead-time control input. When this input is at the same level as V_{REF}, the output transistors are off. As pin 4 drops to 0V, the dead-time decreases to a minimum. At switch on, the 10μF capacitor between V_{REF} (pin 14) and pin 4 is discharged. This prevents the output transistors in IC1 from switching on. The 10μF capacitor then charges via the 47kΩ resistor and so the duty cycle of the output transistors slowly increases until full control is gained by the error amplifier. This effectively provides a soft start for the converter.

The complementary PWM outputs at pins 10 and 9 of IC1 are fed to MOSFET drivers IC2a and IC2b, which drive the gates of Q1 and Q2. Note also the 100nF capacitor and the three 4700μF low-ESR capacitors between the centre tap of the transformer primary and the ground. These are included to cancel out the inductance of the leads which carry current to the transformer. They effectively provide the peak current required from the transformer as it switches.

MOSFET rectification

As previously mentioned, the AC from the transformer secondary is rectified by MOSFETs instead of a conventional diode bridge. This increases the overall efficiency of the DC-DC Converter.

The rectification process employs both the intrinsic diodes of the MOSFETs and their normal channel conduction. The intrinsic diode in a MOSFET is a reverse-connected diode that is part of the substrate layer. Originally, these intrinsic diodes were notoriously slow acting, but are now quite fast. Now, if the MOSFETs were prevented from conducting, their intrinsic diodes are connected to operate in the same way as a conventional bridge rectifier. The MOSFETs themselves are then controlled to act as 'helpers' for each diode, switching on when the intrinsic diodes begin to conduct and switching off just before reverse conduction.

Each MOSFET is controlled using an IR11672 secondary side driver (SSD). Each SSD monitors the voltage across its MOSFET to determine when to switch the MOSFET on or off via its V_{GATE} output.

When the voltage between drain and source is greater than –50mV, the MOSFET is switched on to bypass the intrinsic diode. When the voltage drops below -6mV, the MOSFET is switched off.

Using the MOSFETs saves valuable power compared to conventional diode rectifiers. For example, at a current of 3.5A, a Vishay V10150C Schottky diode would have a forward voltage close to 0.9V, resulting in a power loss of 3.15W for each diode.

By using the specified IRFB23N15 MOSFETs, the voltage drop at 3.5A is less at 0.25V, giving a power loss of 875mW. Overall, the Schottky diode rectification would have a 6.3W loss compared to 1.75W for the MOSFET rectifiers; remember that only two diodes are conducting at any one time. The low power dissipation means that these MOSFETs do not require heatsinking and the higher efficiency means less battery current for a given power output.

Of course, there is some power loss associated with the MOSFET drivers. This amounts to about 267mW for the four devices in the bridge.

The IR11672 includes a minimum on-period to prevent the MOSFET switching off immediately it switches on, which could otherwise happen due to the decreased voltage between drain and source. The minimum on time is set by the resistance at the MOT (Minimum On Time) terminal. Using the 75kΩ resistor, this is around 3μs.

Note that the IR11672 is designed for high-frequency switchmode supply rectification up to 500kHz.

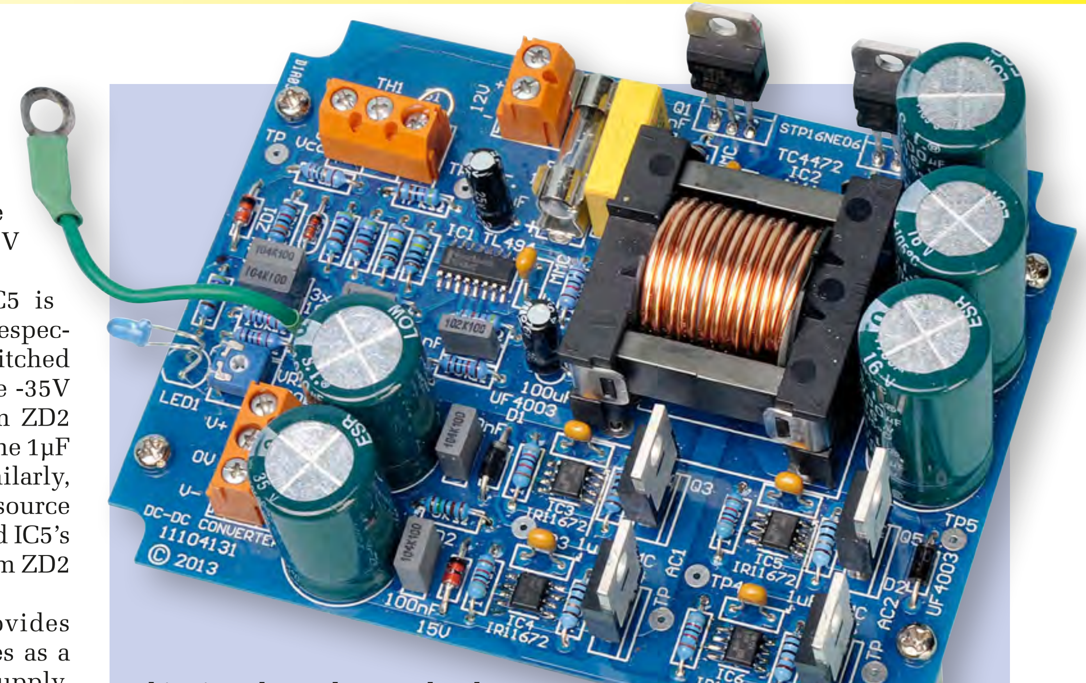
Power for each IR11672 is derived from the -35V supply rail via a 1.5kΩ resistor that feeds 15V Zener diode ZD2. The initial -35V supply is obtained by the rectification provided by the intrinsic diodes in the MOSFETs. Then, as each IR11672 receives a

supply, rectification using the switched MOSFETs begins. Both IC4 and IC6 share the same common 15V supply via ZD2. This is possible because these ICs also share the common -35V supply as their negative rail.

The supply for IC3 and IC5 is derived via diodes D1 and D2 respectively. When MOSFET Q4 is switched on, Q3's source is pulled to the -35V supply rail and so power from ZD2 can flow through D1 to charge the 1µF supply capacitor for IC3. Similarly, when Q6 is switched on, Q5's source is pulled to the -35V supply and IC5's supply capacitor is charged from ZD2 via D2.

Indicator LED (LED1) provides power indication. It also serves as a minimum load for the +35V supply. This minimum load is required to match the load on the -35V supply that delivers power to Zener diode ZD2. Since it is the +35V supply that is monitored with IC1 for voltage regulation, the minimum load ensures that the PWM drive to maintain voltage regulation is sufficient to maintain the -35V supply.

For correct operation, it is important that this minimum load is not disconnected. So, if LED indication is not required, the LED connections on the PCB should be bridged to ensure that the LED resistor is still connected between the +35V supply and ground.



This view shows the completed PCB assembly. It's earthed to the metal case via an earth lead soldered to TP GND.

Construction

All the parts for the CLASSiC DC-DC Converter are mounted on a double-sided PCB available from the *EPE PCB Service*, coded 11104131, and measuring 110mm × 85mm. This fits neatly inside a metal diecast case measuring 119mm × 94mm × 57mm. The diecast case not only makes for a rugged assembly, but also provides shielding plus heatsinking for Q1 and Q2.

> **CAUTION**
>
> It's a good idea to switch off and let the 1000µF output filter capacitors discharge (ie, blue LED out) before connecting (or disconnecting) this DC-DC Converter to an amplifier.
>
> It's also a good idea to avoid touching the ±35V (70V total) supply rails during operation to avoid the possibility of a shock.

Fig.4 shows the parts layout on the PCB. Begin the assembly by installing IC1-IC6. These are all SMDs in SOIC packages and are quite easy to solder in place due to their (relatively) wide 0.05-inch pin spacing. Each IC is mounted on the top of the PCB and must be oriented as shown on the overlay diagram of Fig.4.

To solder an IC in place, align its leads over the PCB pads and tack solder pin 1 first. That done, check that the device is correctly aligned. If not, remelt the solder and adjust it as necessary. The remaining pins are then soldered, starting with the diagonally opposite pin (pin 16 or pin 8), after which you should resolder pin 1.

Don't worry if you get solder bridges between adjacent pins during this process. These bridges can be quickly cleared using solder wick – just press the solder wick against the bridge using a hot soldering iron. A dab of no-clean flux paste will aid this process.

Once all the ICs are soldered in, the next step is to install the remaining low-profile parts. Note that component values shown on Fig.4 are for a 12V supply. If you wish to use a 24V supply, then it will be necessary to change a few component values, as detailed in the accompanying panel.

Start with the resistors, diodes and Zener diodes. Table 1 shows the resistor

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	3	1MΩ	brown black green brown	brown black black yellow brown
❏	4	75kΩ	violet green orange brown	violet green black red brown
❏	2	47kΩ	yellow violet orange brown	yellow violet black red brown
❏	1	13kΩ	brown orange orange brown	brown orange black red brown
❏	7	10kΩ	brown black orange brown	brown black black red brown
❏	3	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❏	1	1.5kΩ	brown green red brown	brown green black brown brown
❏	7	10Ω	brown black black brown	brown black black gold brown

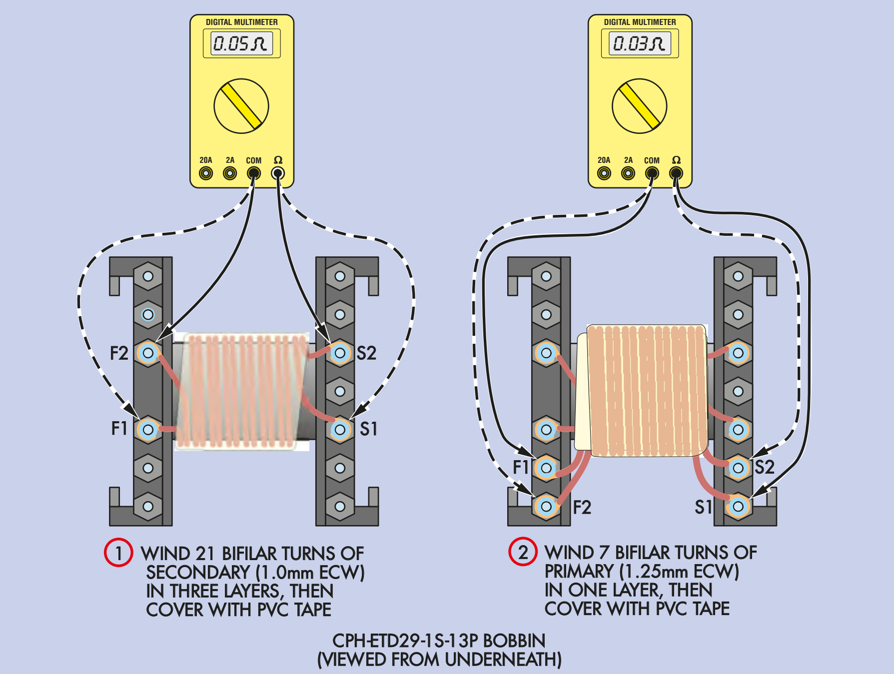


Fig.5: the winding details for transformer T1. The secondary is wound first using 21 bifilar turns of 1mm-diameter enamelled copper wire and is covered with a single layer of insulation tape. The primary is then wound on using seven bifilar turns of 1.25mm enamelled copper wire – see text.

Running the DC-DC Converter from 24V

Although we have not tested this DC-DC Converter at 24V, it can be done with some circuit changes. However, 24V operation is not ideal because the winding wire needs to be a smaller diameter so that the extra turns required can fit on the transformer bobbin.

For 24V operation, the secondary is wound with 21 turns of 0.8mm enamelled copper wire. The primary is then wound with 14 turns of 1mm enamelled copper wire. Note that this has to be run in two layers and so once completed, the wires will need to be run back across to the other side of the bobbin (ie, at right angles to the windings on the underside) to return the wire to the finish terminals.

In addition, the fuse must be changed to 5A, the capacitors changed from 4700µF 16V to 1000µF 35V, the 10Ω resistor for ZD1 changed to 1kΩ and the 13kΩ resistor at pin 2 of IC1 changed to 36kΩ. The parts list below shows the new parts.

Parts list changes for 24V operation

- 1 M205 5A fast blow fuse (F1) (instead of 10A)
- 5 1000µF 35V (instead of 3 × 4700µF 16V PC low-ESR electrolytic and 2 × 1000µF 35V PC low-ESR electrolytic)
- 1 1kΩ 0.25W resistor for ZD1 (instead of 10Ω)
- 1 36kΩ 0.25W resistor (instead of 13kΩ at pin 2, IC1)
- 1 2.6m length of 0.8mm-diameter enamelled copper wire for T1's secondary
- 1 1.8m length of 1mm-diameter enamelled copper wire for T1's primary

colour codes, but you should also check the values with a multimeter, as some colours can be difficult to distinguish.

Be sure to orient the diodes and Zener diodes as shown on Fig.4. The Zener diode type numbers are shown in the parts list.

The PC stake at TP GND is next on the list, followed by LED1. The latter is mounted with its leads bent down by 90°, so that its lens can later be pushed through a matching hole in the side of the case. To install it, bend its leads down about 3mm from its body, then solder it in position so that the centre line of its body sits about 9mm above the PCB.

Be sure to install the LED with the correct orientation. Its anode lead is the longer of the two.

MOSFETs Q1-Q6 can now go in. These should be installed so that the tops of their metal tabs are 20-25mm above the PCB.

Follow with the capacitors. The electrolytic types must all be oriented with the correct polarity (ie, with the negative side towards the left edge of the PCB). Once they're in, install trimpot VR1, then fit screw terminal blocks CON1, CON2 and CON3.

Now fit the fuse clips. These each have an end stop at one end, so that the fuse will not slip out when installed. Make sure these end stops go to the outside, otherwise you will not be able to later install the fuse.

Transformer winding

The PCB assembly can now be completed by winding and fitting the transformer. Fig.5 shows the winding details for the 12V version (refer to the accompanying panel for the winding details for the 24V version).

The secondary windings are wound on the bobbin first. Begin by cutting a 2.6m length of 1mm-diameter enamelled copper wire into two 1.3m lengths. That done, strip 5mm of the enamel insulation from one end of each wire using a hobby knife, then solder these wires to terminals S1 and S2 (start) as shown in Fig.5 (these go on the side with the seven terminals).

Now carefully wind on seven bifilar turns (ie, both wires laid side by side) to the opposite side of the bobbin, then another seven turns back towards the start terminals and finally another seven turns back to the opposite side (ie, 21 bifilar turns in all). Once all the turns are on, secure them in place using a single layer of insulation tape, cut to fit the width of the bobbin.

Now set your multimeter to read 'ohms' and use it to determine which wire is connected to S1. That done, trim this wire to length, strip 5mm of enamel insulation from the end and solder it to terminal F1. The other wire is then connected to F2.

Finally, use your multimeter to confirm that there is close to zero ohms between S1 and F1 and close to zero ohms between S2 and F2. Check also that there is a high impedance (>1MΩ)

between the windings, eg, between S1 and S2.

The primary winding is also bifilar wound but consists of just seven turns of 1.25mm enamelled copper wire. Note that the orientation of the bobbin is also important when installing this winding.

First, check that the bobbin is oriented so that the side with the six terminals is to the left, as shown in Fig.5 (ie, with the terminals facing towards you). That done, cut a 900mm length of 1.25mm enamelled copper wire in half, strip one end of each wire and solder them to the primary S1 and S2 terminals.

Now wind on seven bifilar turns in the direction shown, taking care to ensure that the wires are close together (otherwise they won't fit into the bobbin). Cover this winding with another layer of insulation tape, then identify which wire connects to S1 and connect it to F1. The other wire is then connected to terminal F2.

Note that the primary F1 and S1 terminals are diagonally opposite each other, as are S2 and F2. By contrast, S1 and F1 are directly opposite each other for the secondary winding (as are S2 and F2).

Once again, use a multimeter to confirm that S1 and F1 are connected, that S2 and F2 are connected, and that there is a very high impedance between the two windings. Check also that there is no connection between any of the primary and secondary windings.

Once the windings are in place, the transformer assembly is completed by sliding the two ferrite cores into the bobbin and securing them in place using the supplied clips. The transformer can then be installed on the PCB.

Parts List

1 double-sided PCB, available from the *EPE PCB Service*, code 11104131, 110mm × 85mm
1 diecast box, 119mm × 94mm × 57mm
1 ETD29 transformer (T1) (1 × 13-pin former [element14 Cat. 1422746], 2 × N87 cores [element14 Cat. 1781873], 2 × clips [element14 Cat. 178507]
1 thermostat switch (60°C, normally closed)
2 IP68 cable glands, 4-8mm cable diameter
1 2-way screw terminals (5.08mm pitch) (CON1)
2 3-way screw terminals (5.08mm pitch) (CON2,CON3)
2 M205 PCB-mount fuse clips
1 M205 10A fast-blow fuse (F1)
1 SPST or SPDT toggle switch (S1) (optional – see text)
4 M3 × 9mm tapped spacers
2 TO-220 silicone insulation washers
2 insulating bushes
2 M3 × 10mm screws
6 M3 × 6mm screws
4 M3 × 6mm countersunk screws
4 M3 nuts
1 solder lug
1 2.6m length of 1mm enamelled copper wire (for T1 secondary)
1 900mm length of 1.25mm enamelled copper wire (for T1 primary)
1 length of 24/0.2mm (0.75mm^2 cross section) figure-8 cable
3 lengths of 19/0.18mm (0.48mm^2 cross section) or 14/0.2mm (0.44mm) wire
1 200mm length of medium-duty hookup wire
1 PC stake (TP GND)

Semiconductors
1 TL494CDR SOIC-16 switch-mode pulse-width modulation controller (IC1)
1 TC4427ACOA SOIC-8 Dual MOSFET Driver (IC2) (element14 Cat. 1467705)
4 IR11672ASPBF SOIC-8 Smart Rectifier Controller (IC3-IC6) (element14 Cat. 1827123)
2 STP60NF06 N-channel MOSFETs (Q1,Q2)
4 IRFB23N15DPBF 150V, 23A N-channel MOSFETs (Q3-Q6) (element14 Cat. 8648735)
2 UF4003 fast rectifier diodes (D1,D2)
1 1N4148 switching diode (D3)
1 16V 1W Zener diode (1N4745) (ZD1)
1 15V 1W Zener diode (1N4744) (ZD2)
1 3mm blue LED (LED1)

Capacitors
3 4700µF 16V low-ESR electrolytic
2 1000µF 35V low-ESR electrolytic
1 100µF 16V electrolytic
1 10µF 16V electrolytic
6 1µF 50V monolithic multilayer ceramic (MMC)
1 100nF X2 class 275VAC MKP metallised polypropylene
5 100nF 63/100V MKT
1 1nF 63/100V MKT

Resistors (0.25W, 1%)

3 1MΩ	6 10kΩ
4 75kΩ	3 4.7kΩ
2 47kΩ	1 1.5kΩ
1 13kΩ	7 10Ω

1 100kΩ mini horizontal trimpot (VR1)

Preparing the case

You now have to drill holes in the diecast box to mount the PCB and to mount Q1 and Q2 and the thermal switch. Another hole is required for the LED, while two large holes are required to accept cable glands.

First, sit the PCB assembly inside the box and mark out the four mounting holes. Drill these out to 3mm in diameter and countersink them from the outside to suit the specified countersunk screws.

That done, attach four M3 × 9mm nylon spacers to the PCB assembly using M3 × 6mm screws, then sit the PCB inside the diecast box. Once it's in position, mark out the mounting holes for the tabs of MOSFETs Q1 and Q2 plus a hole at one end to accept the indicator LED.

Drill these out to 3mm in diameter, then slightly countersink the holes for Q1 and Q2 to remove any sharp edges. This is necessary to prevent damage to the silicone insulating washers that fit between the MOSFET tabs and the case (a sharp edge could puncture a washer and short a metal tab to the case).

The cable glands are placed 15mm down from the top of the case and 20mm in from the sides (see photo). The thermal cut-out is mounted midway between the two cable glands, with its top mounting hole 7mm down from the top edge of the case.

It's a good idea to solder an M3 nut to one lug of the thermal cut-out. This can then be lowered into the mounting position, making the unit easier to attach when the PCB is in place.

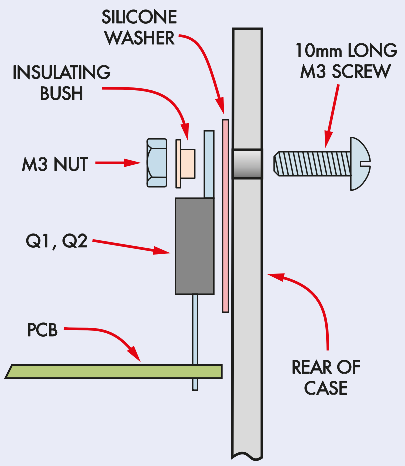


Fig.6: the mounting details for MOSFETs Q1 and Q2. The metal tab of each device must be isolated from the case using an insulating bush and a silicone washer.

Using the converter to power the SC480 amplifier

If you want to run a pair of SC480 amplifier modules using this DC-DC Converter, you can do so, but they will give slightly less than their specified power output since they were originally designed to run from ±40V rails. However, they will run quite happily from ±35V.

Modifying the CLASSiC-D Amplifier For ±35V rails

As presented in the November and December 2013 issues of *EPE*, the CLASSiC-D Amplifier is designed for ±50V (or ±55V) supply rails. However, if you intend using this DC-DC Converter to power the amplifier, you need to make a few changes to the amplifier to suit the converter's lower ±35V supply rails.

This involves changing several resistors and Zener diodes, as shown in Table 1 on page 30 of the December 2013 issue (ie, in the article describing the construction of the CLASSiC-D Amplifier module). The new Zener diode type numbers are shown in Table 2.

Once the necessary parts have been changed in the amplifier, the supply wires from the DC-DC Converter can be connected to it using three lengths of 19/0.18mm (0.48mm^2 cross section) or 14/0.2mm (0.44mm^2) wire. Make sure the connections are made with the correct polarity.

Once all the holes have been drilled, install the PCB assembly in the case and secure it using four countersunk screws.

Attaching Q1 and Q2

Q1 and Q2 are each attached to the side of the case using an M3 × 10mm screw and nut, along with a silicone insulating washer and an insulating bush. Fig.6 shows the details. Do the screws up firmly, then use a multimeter to check that both tabs are correctly isolated from the case.

You can do this by measuring the resistance between the case and the MOSFET tabs. You should get a high ohms reading in each case, but the meter may initially show a low ohms reading as various on-board capacitors charge up when the probes are connected. A permanent zero ohms reading means that there is a short which has to be fixed.

The case itself is earthed to the GND PC stake on the PCB via a short length of hook-up wire. That's done by first attaching a solder lug to one end of the wire, then attaching this to the case using the same mounting screw that's used to attach the top lug of the thermal cut-out. The other end of the wire is then soldered to the GND stake.

Once it's in place, fasten the bottom mounting lug of the thermal cut-out to the case, then solder two 80mm-long leads to its terminals and insulate these with heatshrink. The other ends of these leads can then be stripped and connected to the TH1 terminals on CON2.

The S1 switch terminals on CON2 can either be connected to an external switch or simply bridged with a short piece of tinned copper wire. The switch (or bridging wire) does not carry significant current (less than 50mA), since it doesn't carry the full DC-DC Converter current.

Basically, S1 will probably only be needed if there's no power switch for the external power supply.

Completing the assembly

The assembly can now to completed by installing fuse F1 and connecting the power supply leads. The supply leads can be made using a suitable length of 24/0.2mm (0.75mm^2) figure-8 wire. Connect the striped lead to the negative terminal of CON1 and the other lead to the positive terminal.

You can use a pair of needle-nose pliers to push the wires into their terminals on CON1.

Testing

Before connecting the external supply, go over the assembly carefully and check that the parts are all correctly positioned. In particular, check that the electrolytic capacitors are the right way around as these things have a nasty habit of exploding if they are installed with reverse polarity.

That done, wind trimpot VR1 fully anticlockwise, then fit the lid on the case (just in case an electrolytic is in the wrong way around).

If possible, use a current-regulated power supply to initially test the DC-DC Converter. If you don't have one, then a non-regulated supply or a 12V battery can be used. Be sure to get the supply polarity correct; if you connect it the wrong way around, the fuse will blow.

Once it's hooked up, apply power and let the unit run for several minutes. If it powers up safely (ie, no explosions from capacitors), you can then remove the lid and check the voltages between the 0V and the +35V and -35V terminals on CON3. With VR1 wound fully anticlockwise, you should get around +10V and -10V on these terminals.

Assuming all is well, carefully rotate VR1 clockwise until you get +35V and -35V readings. **Do not set the outputs any higher than ±35V, as the output capacitors are not rated for higher voltages (ie, they only have a 35V rating).**

Finally, the three output leads can be made up using 24/0.2mm wire and connected to CON3. The other ends of these leads can then be fitted with coloured heatshrink sleeves to identify them: red for +35V, green for 0V (GND) and blue for -35V.

Your new *DC-DC Converter* is now ready for use with the *CLASSiC-D Amplifier*. However, before connecting it up, the amplifier needs a few minor modifications in order to operate from ±35V rails – see the above panel.

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AAAGH!

Does your Digital Multimeter lack an auto power-down facility? Many don't – and if you forget to turn it off, next time you go to use it you might be tempted to say naughty words. This little circuit, which will cost just a couple of pounds, will stop a DMM chewing through batteries when you forget to turn it off.

While this auto simple power-off circuit is intended for the tiny QM1502 DMM, this could be applied to many other battery-operated devices.

By Stan Swan

Shoppers may have spotted the cute new orange QM-1502 mini DMM (digital multimeter) and wondered if such throwaway-priced 'toys' can be serious!

At its bargain price – a fiver or so – it's hard to know if one should laugh or cry at such trivial test gear prices. I recall (as an early teen) paying hundreds in today's money for a *far* inferior analogue meter. For schools and hobbyist needs they look extremely appealing – you can never have too many multimeters of course!

But, even at such a low cost, are they worth a punt? Although superior meters abound in the £30-40 range (and should certainly be considered for those serious about electronics), this little DMM merits a closer look for newcomers, schools and hobbyists.

With dimensions of just 94(H) × 46(W) × 26(D)mm it's almost laughably tiny (the footprint being smaller than a credit card) but range settings are very clear and the display is bright and clear.

Build is surprisingly good, with a sturdy switch action and current drain an astoundingly low 250µA from the small cylindrical A23 12V battery. A full set of normal electrical readings, even including transistor gain, is featured.

The (unfused) 10A DC current range remains usefully connected even with the meter turned off – handy perhaps for occasional monitoring of a photovoltaic solar array or battery charger.

The 12V supply voltage is not critical and the DMM runs well from a fresh 9V battery, with the 'low batt' symbol only showing at around 7V. Demand current, which 'surged' to 400µA on resistance with shorted leads, otherwise remains near 250µA.

Aside from newcomers, schools and toolbox spare use, the DMM is also suitable as an inbuilt panel meter. That's right – just switch it to the setting you want, internally connect leads and supply and build it into the project!

An A23 battery might be rated at 12V, but the opened-up view at right shows why they don't have much capacity – they're merely eight button cells packaged together.

I forgot to turn the DMM off . . . again!

Note, however, that it's not possible to power the DMM from the same circuit that you are monitoring. This arises because many basic DMMs use a classic ICL7106 COB (chip-on-board) for measuring and display. The 'COM' socket on such meters is at 3V lower potential than the +ve terminal of the battery inside, as such an arrangement also allows negative voltages to be measured.

So what's the downside of such a cheap meter?

Several weak points emerge. For example, the meter sensitivity (or insertion resistance, if you like) is only around 1MΩ (most DMMs now are far better) and the supplied probes are low quality – **do not trust them for mains work!** We also found some difficulty in inserting the leads into the multimeter sockets – they do go in, but...

The leads can readily be upgraded (you'll probably pay as much for better leads than the whole DMM, perhaps more), Or you might like to replace the test probe ends with some more sturdy crocodile clips.

Even with decent test leads we still have a major reservation about safety. While the DMM has ranges for 500V AC and DC, we'd be very hesitant about using it for this type of measurement.

In fact, we'd go so far as to say it should only be used on low voltages – 50V AC or DC – and we've even prepared a warning label to stick on the meter.

No auto off

However, the meter's most annoying attribute (or non-attribute!) is the lack of auto-power-off. Despite the multimeter's low current drain, the low capacity of 12V A23 batteries (which are merely eight button cells packaged together) means that you're likely be plagued by flat batteries, especially if you forget to turn it off.

And A23 batteries can be elusive and costly (often around £3 to £5) – which may exceed the cost of the meter!

As alkaline A23 batteries typically have a 55mAh capacity, only a few dozen hours or so of operation will result before the supply drops too low. Although tolerable for a conscientious user, this equates to approximately a weekend, so failure to turn off the meter on Friday will likely see it flat by Monday.

Educators who've found their class meter batteries dead mere minutes before 30 surly youths arrive for a Monday school lab session will keenly appreciate this particular 'electro-angst'.

Even with meagre supply needs, it makes no sense to leave devices wastefully on when battery replacement costs are high.

What to do?

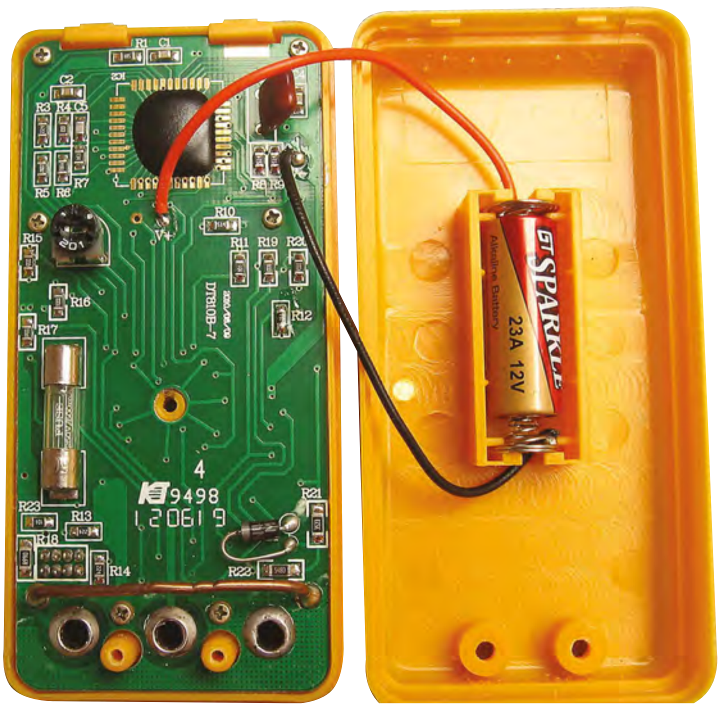
Several supply workarounds were considered, with an eye to cost effectiveness – it's unjustified spending much more than the meter cost on enhancements!

Space inside the meter case is tight, but there's enough for some additional compact circuitry, although simpler approaches may appeal (if only for constructional ease).

In approximate order of complexity, these include:

External 9V battery supply: Alkaline types of ~500mAh capacity (of which perhaps half will be available before the supply falls below 7V), are cheaper than A23 (but not much) and are very widely available. They won't fit inside the QM-1502 case, but could be readily mounted externally, perhaps along with a supply switch. For many users this approach may be appealing.

Case mounted switch: A dedicated supply switch can also prolong the life of the DMM's rotary switch, as a pre-selected range can remain ready for immediate use at power up.



This is what the DMM looks like when it's opened up. Shown here very close to life size, you can see that there's room on the inside back of the case to add a simple auto power-off circuit.

(Many a DMM fuse is blown by 'knob twiddlers' when meter current ranges are selected with the meter paralleled to the supply.) In conjunction with a low drain LED (often still visible at a mere few hundred microamps), a still-powered meter would then readily be noted in a dark storage cupboard.

Solar Power: Although using a few tiny photo-voltaic cells from cheap calculators or solar garden lights (most provide ~3mA at several volts) is tempting, an array to supply >7V would be difficult to neatly mount on the front of this small DMM. Also, meters are often used in poorly lit places indoors.

Orientation switch: Mercury position switches are relatively costly and may annoy users when the meter is in unexpected working positions.

Auto power off – microcontroller or IC: The popular PICAXE-08M microcontroller can shut down totally after some minutes, but a sleeping PICAXE will draw tens of microamps, which over time will still drain batteries.

Such an approach is rather an overkill anyway, as of course a micro can do far more! Additionally, the cost of the IC and extra components will likely exceed that of the DMM.

'Joule thief' step up: Solar garden lamps use step-up circuitry to drive a 3-4V white LED from a single AA(A) sized battery. Although higher voltages are possible, they're at very reduced currents and with rough output, requiring smoothing and regulation.

Auto-power-off capacitor discharge: As users are now familiar with such modern devices as cameras, cell phones and PCs going 'touch to revive', a simple switched discharging electrolytic was considered. Quick tests with a 4700µF electrolytic confirmed several minutes hold up until the ~7V 'low battery' display came up.

This is readily verified by Q = I × t = V × C, when a 250µA drain at 12V should fall in one time constant (T) to 1/e (37%) of the original voltage (12V × .37 = ~ 4V. Hence the time constant = 12 × 4700 x 10^{-6}/(250 x 10^{-6}) = ~200 seconds.

This approach could suit push switch operation for quick checks (perhaps of circuit charge/discharge currents or supply voltages) but power will only be held on for few minutes. This time will be too short for most users, and can only be extended with larger value capacitors (10,000µF+), or even super-caps,which will be bulky and perhaps costly.

Auto-power-off – FET capacitor discharge: eventually, after going through lots of options, we decided that a FET capacitor discharge circuit showed the most promise and has been the approach adopted.

Small signal FETs

High gain Darlington bipolar-based auto-power off circuits exist, but the popular (and cheap) 2N7000 (N-Channel enhancement-mode FET with an insulated gate is superior as, being a FET it has negligible gate current.

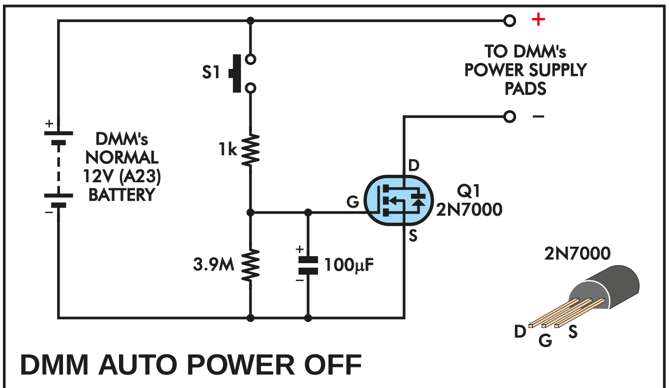


Fig.1: the circuit is simply a switch (Q1) which is turned on by pressing S1 and it turns the DMM off once the 100µF capacitor discharges, to conserve the battery.

A major practical benefit of such gate supply switching is that only low value (10-100µF range) electrolytics are needed, which are cheaper and fit better in the DMM's case than larger types.

A breadboard trial with the 2N7000 verified that a momentary push on the switch, with a 100µF electrolytic, paralleled with a 3.9MΩ across the gate, held the meter on for about 10 minutes before the low-battery symbol appeared.

This period should be enough for most users, but could be readily altered with different value discharge resistors, An A23 battery, with its 350µA drain could stretch to perhaps hundreds of such test sessions.

Simple components are used, and the total bill of materials should only be a few pounds. The benefit of such an enhancement may be educational as well as financial, especially for those fresh to electronics.

A 'hands on' understanding of RC discharge and FET action should result and organising the few components to fit the DMMs interior may help new comers develop skills with compact circuitry.

Construction

For such a simple circuit, a PCB is hardly warranted (and would likely cost as much as the DMM).

Therefore a small (5×5 hole) Veroboard offcut was used and the components connected as shown in the wiring diagram. The electrolytic capacitor will not fit into the case if soldered onto the Veroboard in the normal way – it is laid over off the Veroboard and parallel to it, as shown.

The supply wiring (ie, from battery to the DMM PCB) was then connected as shown in the diagram. You only

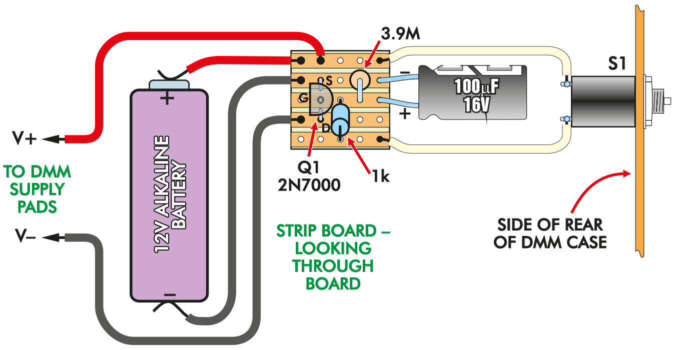
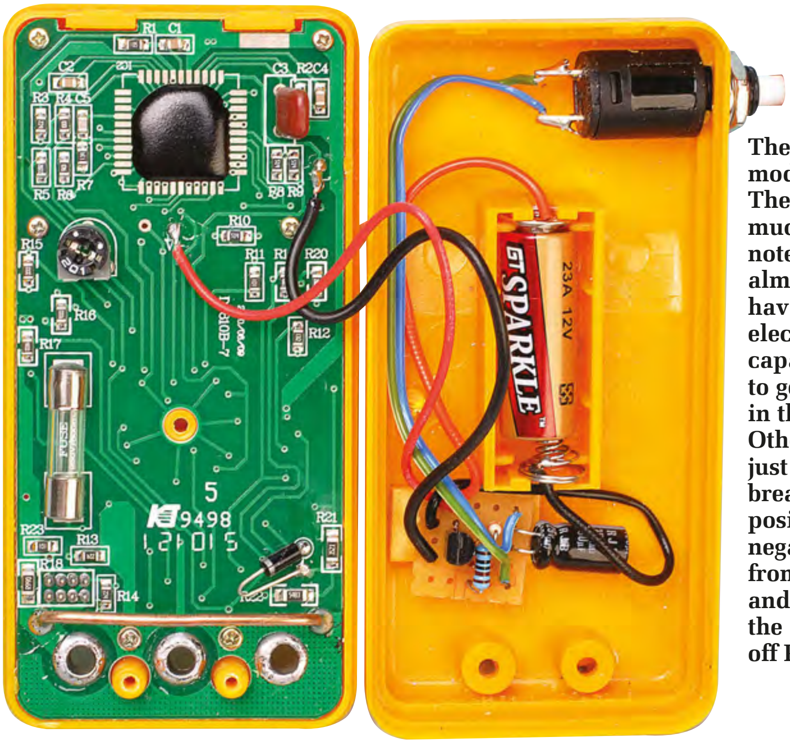


Fig.2: a suggested Veroboard layout and wiring diagram. The Veroboard and 100µF electrolytic capacitor can be secured to the DMM case with double-sided adhesive.



The finished modification. There's not much to it, but note that you'll almost certainly have to lay the electrolytic capacitor over to get it to fit in the case. Otherwise, it's just a matter of breaking the positive and negative leads from the battery and inserting the auto turn-off PCB.

need to unsolder two of the wires (ie, those going from battery to the PCB) and connect wires from your Auto Power-Off switch in their place.

Finally, carefully drill a hole in the side of the case (back section) for the pushbutton switch (its diameter will depend on the exact switch you use).

There is a ridge all around the case and unfortunately the hole needs to go through the case where the ridge steps down. But once tightened properly, this should not be a problem.

Depending on the size of your switch, you may need to mount the Veroboard underneath the battery compartment – if you do, make sure it's as close as possible to the battery to avoid interference with the current shunt in the DMM (the thick copper wire near the terminals at the bottom of the case).

Similarly, make sure it doesn't interfere with the on-board fuse.

We used a switch probably larger than necessary, originally to maintain the isolation between contacts and outside. However, with our comments about using the DMM on 50V or less, a much smaller switch will suffice.

One further enhancement makes the meter more 'user friendly': marking the setting arrow more boldly with a spirit-based pen ensures correct settings.

While the arrow and markings are obvious in bright light, they are much less so in dim light!

Speaking of light, we've found that some of these meters are sensitive to bright sunlight (affecting readings). This can be simply cured with a piece of black electrical tape over the back of the chip (the black blob!).

Parts List – DMM Auto Power Off

1 NO momentary pushbutton switch
1 2N7000 FET or equivalent
1 100µF 16V electrolytic capacitor
1 scrap of Veroboard (5 × 5 holes)
Short lengths of red and black hookup wire

Resistors (1/8 or 1/4W, 5%)
1 3.9MΩ (orange white green gold)
1 1kΩ (brown black red gold)

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Finally: don't twiddle the pot!

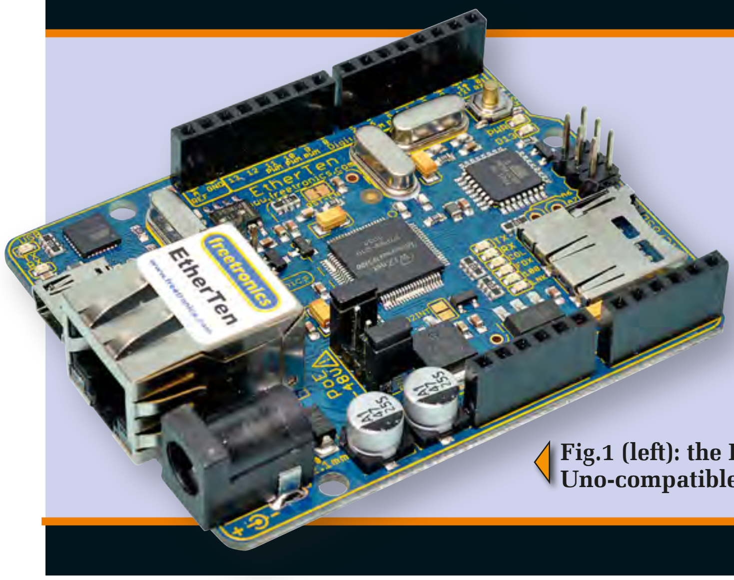
Note – the potentiometer, or variable resistor, in the DMM is used for calibration, so avoid altering its factory setting as re-calibration may then be needed and you won't have the equipment necessary to do this.

Noting our comments about safety, this warning label can be printed and glued to the top front of the case, as shown earlier.

Control relays over the Internet with Arduino

Turning items on and off remotely via the Internet has generally been a complex and expensive task due to the hardware and knowledge required – not any more! Here we show how easy and inexpensive it can be to control four or more relays over the Internet using open-source Arduino-based hardware.

By JOHN BOXALL



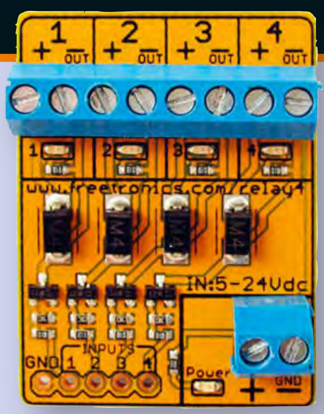


Fig.2: the Freetronics RELAY4 relay driver module. It interfaces directly to the EtherTen module and uses FETs to switch external relays.

Fig.1 (left): the Freetronics EtherTen module is Arduino Uno-compatible and has an onboard Ethernet interface.

IT'S NOT DIFFICULT to remotely control relays via the Internet. In this article, we'll first look at the hardware required, then explain the software and network requirements. After that, we'll look at how commands are sent over the Internet using a web browser to control the relays.

If you are unfamiliar with the Arduino environment, please visit the device's homepage at: **www.arduino.cc**

The hardware

The heart of the system is an Arduino Uno-style board with an Ethernet shield. In this case, we have used a Freetronics EtherTen board which conveniently combines both into a single unit, thereby saving space and money – see Fig.1.

The EtherTen board can control up to four relays via a Freetronics RELAY4 4-channel relay control module – see Fig.2. This module interfaces directly to the EtherTen Arduino board and uses FETs to switch the relay coils. It also includes reverse-connected power diodes to suppress back-EMF pulses when the relays are turned off.

Connecting the relay module to the Arduino board is very simple:

- *Input 1 to Arduino D2*
- *Input 2 to Arduino D3*
- *Input 3 to Arduino D5*
- *Input 4 to Arduino D6*
- *Logic GND to Arduino GND*

Note that when using an Ethernet-enabled Arduino board, digital pins 10-13 are used by the Ethernet interface and can't be used for other purposes. And in the case of the EtherTen board, digital pin 4 is used for the microSD card.

Note that, for this project, we don't use digital pin 8 either and we'll explain the reason for this shortly.

The next consideration is the power supply for the relay coils. Although there is a 5V power supply available from the Arduino board, it's unable to supply enough current to drive most conventional relay coils. What's more, it cannot be used to power relays with 12V (or higher) coils. In

either case, you will have to connect an external DC power supply with the required ratings to the RELAY4 board's power terminals (bottom-left of Fig.3).

On the other hand, if you can keep the current draw under 150mA and are using solid-state 5V relays with very low switching currents, the on-board Arduino 5V supply will be enough.

With a 5V supply, the RELAY4 board itself draws around 13mA with all LEDs on. Add four relays drawing just 20mA each and you can comfortably power the lot from the Arduino. In that case, connect the positive pin from the RELAY4 power terminal to the Arduino +5V pin.

Testing

You can then test the connections to the RELAY4 board with a simple Arduino sketch (software program) that turns the outputs on and off – as indicated by the on-board RELAY4 LEDs. Once your hardware has been connected, enter and upload the following sketch using the Arduino IDE (Integrated Development Environment):

```
void setup()
{
 DDRD = B11111111; // set PORTD (digital 7~0) to outputs
}

void loop()
{
 PORTD = B01101100; // set D2, D3, D5, D6 HIGH
 delay(250);
 PORTD = B00000000; // set D2, D3, D5, D6 LOW
 delay(250);
}
```

At this stage, all four LEDs should be blinking on and off at 2Hz. If not, check the wiring between the two boards, including the GND line.

Software and network requirements

To control our Arduino over the Internet, we use a free online service called 'Teleduino'. It allows us to send commands to an Arduino board (via the Internet) using simple commands in the form of URLs similar to that used to refer to a web page.

You can find out more at the Teleduino website at: **www.teleduino.org**

To identify an individual Arduino board to the Teleduino service, we use a unique key in the form of a long hexadecimal number. This key is issued by the Teleduino service and is inserted into the Arduino sketch and also into the commands issued to control the board.

To generate a key, simply go to **https://www.teleduino.org/tools/request-key** and complete the required fields. A short time later, your key will arrive via email – remember to store this for later retrieval. It will be a long string of characters, eg, 18F5F4749B058F952ABCDEF8534B2BBF.

The next step is to download and install the Teleduino Arduino library into the IDE. The latest library can be found at: **https://www.teleduino.org/downloads/** Extract the library folder and copy it to the arduino-1.0.1/libraries folder in your IDE installation. If your IDE is running, you will need to restart it in order to use the library.

You now have to prepare the Teleduino sketch for the Arduino board. This sketch connects the Arduino to the

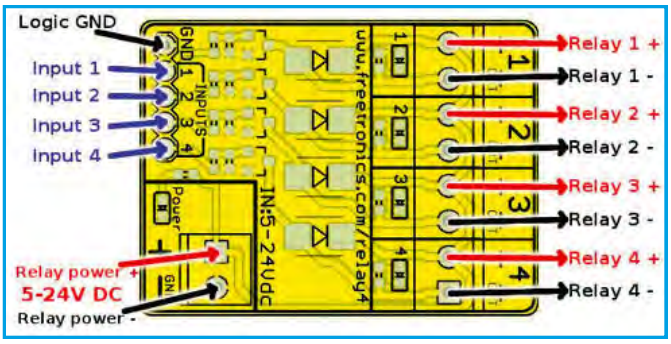


Fig.3: here's how to connect the external hardware and wire the power supply to the relay driver module.

Teleduino server and also executes received commands via the service. The sketch is included with the library, so in the IDE select *File –> Examples –> Teleduino328 –> TeleduinoEthernetClientProxy*.

Before uploading the sketch, the unique Teleduino key needs to be inserted so the Arduino can identify itself to the service. To do this, go to **https://www.teleduino.org/tools/arduino-sketch-key**, enter your Teleduino key into the field and click 'Generate Code'. This will appear as an array in Arduino format as shown, for example, in Fig.4.

That done, scan through the Arduino sketch currently loaded in the IDE, locate the same byte variable (it should start on line 36) and replace the array full of zeros with your Teleduino key array – see Fig.5 (for example).

Once you have modified the sketch as above, upload it to your Arduino as normal. You should also save the sketch so you don't need to repeat the key-insertion process in the future. Note that if you are going to control multiple Arduino boards, you will need multiple Teleduino keys. Just remember to keep track of the key uploaded to each board.

The next step is to test that the Arduino is connecting to the Teleduino service by monitoring the connection status. This can be done using an LED indicator connected via a 560Ω resistor between the Arduino's D8 pin and GND, as shown in Fig.6.

Once the indicator LED is in place, connect the Arduino to your router via a network cable, apply power and watch the LED. After a few moments, the LED will start blinking to indicate the status of the connection to the Teleduino service.

At the time of writing, the following blink parameters are used:

```
byte key[] = { 0xAD, 0xAE, 0x57, 0x43,
               0x1F, 0xC9, 0xB9, 0xD1,
               0xCA, 0x90, 0xEF, 0x71,
               0xE6, 0x14, 0x45, 0xC0 };
```

Fig.4: a Teleduino key array in Arduino sketch format.

```
// The proxy server retrieves the key from the EEPR
byte key[] = { 0xAD, 0xAE, 0x57, 0x43,
               0x1F, 0xC9, 0xB9, 0xD1,
               0xCA, 0x90, 0xEF, 0x71,
               0xE6, 0x14, 0x45, 0xC0 };

// Other required variables
```

Fig.5: the Teleduino key array after insertion into the Arduino sketch.

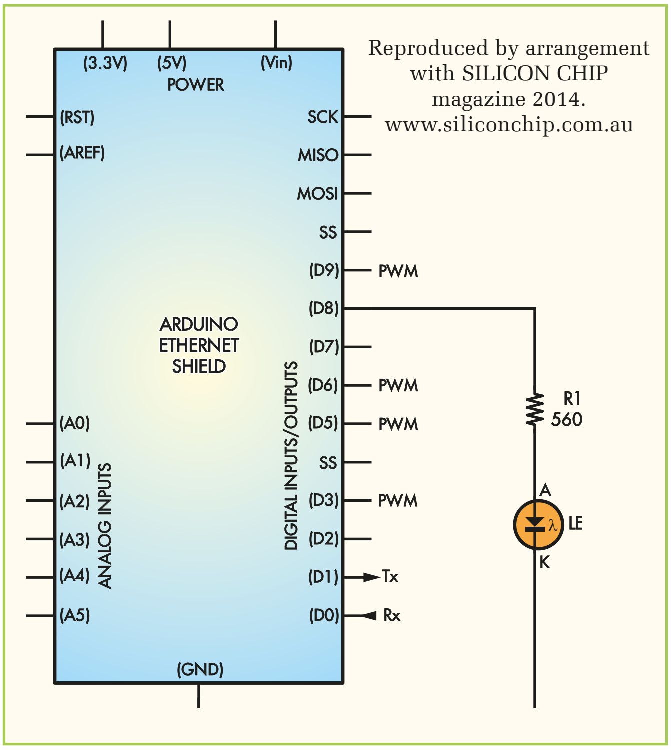


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Fig.6: the status LED is connected between D8 and GND of the Arduino module, as shown here.

- *1 blink: initialising*
- *2 blinks: starting network connection*
- *3 blinks: connecting to the Teleduino server*
- *4 blinks: authentication successful*
- *5 blinks: session already exists for supplied key*
- *6 blinks: invalid or unauthorised key*
- *10 blinks: connection dropped*

It is normal for the LED to work its way up from one to four blinks. After the connection and authentication is successful, the LED will then blink very briefly every 10 seconds or so. This signifies that all is well.

If your LED shows five blinks, just reset the Arduino board. If your LED shows six blinks, check your Teleduino key in the control sketch and re-upload it to the Arduino. And finally, if it blinks 10 times, the Internet connection has dropped out.

Although the above procedure may seem somewhat tedious, it is necessary to establish that everything is working correctly. Once you've done that, the status LED can be removed if desired, but we suggest keeping it to aid troubleshooting if you strike problems in the future.

Default relay settings

The final step in setting up the Teleduino service is to decide what the default settings will be for each of the relays. These are the settings that the relays revert to when the Arduino board is turned on or reset, loses the Internet connection or the network cable is removed.

You can set the defaults after your Arduino has connected to Teleduino by browsing to **https://www.teleduino.org/tools/manage-presets** After entering your Teleduino key, a large selection of options will be displayed. Scroll down to the 'Pins' section (see Fig.7) and change the mode of the Arduino pins you're using to OUTPUT. Then, depending

Pin	Mode	Value	Pin	Mode	Value
0	Unset	Unset	11	Unset	Unset
1	Unset	Unset	12	Unset	Unset
2	1 - output	0	13	Unset	Unset
3	1 - output	0	14	Unset	Unset
4	Unset	Unset	15	Unset	Unset
5	1 - output	0	16	Unset	Unset
6	1 - output	0	17	Unset	Unset
7	Unset	Unset	18	Unset	Unset
8	Unset	Unset	19	Unset	Unset
9	Unset	Unset	20	Unset	Unset
10	Unset	Unset	21	Unset	Unset

Fig.7: this section of the Teleduino presets page allows you to set the defaults for the Arduino's digital I/O pins.

on your needs, you can set the default relay status with the value parameter.

Controlling the RELAY4 module

To control the RELAY4 module, first launch your web browser (on a computer, smartphone or tablet). You can then control the Arduino's digital pins and thus the relays by going to **http://us01.proxy.teleduino.org/api/1.0/328.php?k=999999&r=setDigitalOutput&pin=X&output=Y**

There are three parameters you need to enter into this page. The first is your Teleduino key – simply replace 999999 with your key. The next is the Arduino digital pin to control – replace 'X' with the pin number. And finally, to turn the pin on or off, replace Y with a '0' for off or a '1' for on.

For example, to turn on relay 1, you would use **http://us01.proxy.teleduino.org/api/1.0/328.php?k=999999&r=setDigitalOutput&pin=2&output=1**

To turn it off again, simply change the final '1' to '0'.

You may find it convenient to bookmark the various URLs to make sending commands much easier. Furthermore, the use of URL-shortening services such as **http://bit.ly** can reduce their length to more manageable sizes.

By checking the status LEDs on the RELAY4 board, you can test the pin control without needing to wire up your entire project at the start. Also, when you send a command, the Teleduino server will return a message if the action has been successful or not. If the command worked, an output similar to the following will appear in the web page:

{"status":200,"message":"OK","response":{"result":1,"time":0.2338559627533,"values":[]}}

Conversely, if it was not successful, you will see:

{"status":403,"message":"Key is offline or invalid.","response":[]}

This tells you that the Arduino has lost connection to the Teleduino servers.

Conclusion

Once you have run through the set-up procedure, controlling the relays remotely is quite simple. If you need to control more relays, either add another RELAY4 board or check out the Freetronics RELAY8 board.

Finally, the Teleduino service allows web-based control of much more than your Arduino's digital outputs – refer to **http://www.teleduino.org** for more information.

Win a 16-bit Explorer Development Board

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a 16-bit Explorer Development Board from Microchip. The Explorer 16 is a low-cost, efficient development board designed to evaluate the features and performance of Microchip's new 16-bit PIC24 Microcontroller and dsPIC33 digital signal controller (DSC) families. Coupled with the MPLAB ICD 2 in-circuit debugger, real-time emulation and debug facilities speed evaluation and prototyping of application circuitry. The Explorer 16 features two interchangeable plug-in modules (PIMs), one each for the PIC24FJ128GA010 and the dsPIC33F128GP710 DSC.

It features both PIC24FJ128GA010 microcontroller and dsPIC33F128GP710 digital signal controller PIMs, alpha-numeric 16 × 2 LCD display, interfaces to MPLAB ICD 2, USB, and RS-232, includes Microchip's TC1047A high accuracy, analogue output temperature sensor, expansion connector to access full devices pin-out and breadboard prototyping area, PICtail Plus connector for future expansion boards and the full documentation CD includes user's guide, schematics, and PWB layout.

JANUARY 2014 ISSUE WINNERS:
Mr Richard Rushby from Codeshape, UK.
Mr Ian Williams from Sterling Security Systems Ltd, UK.

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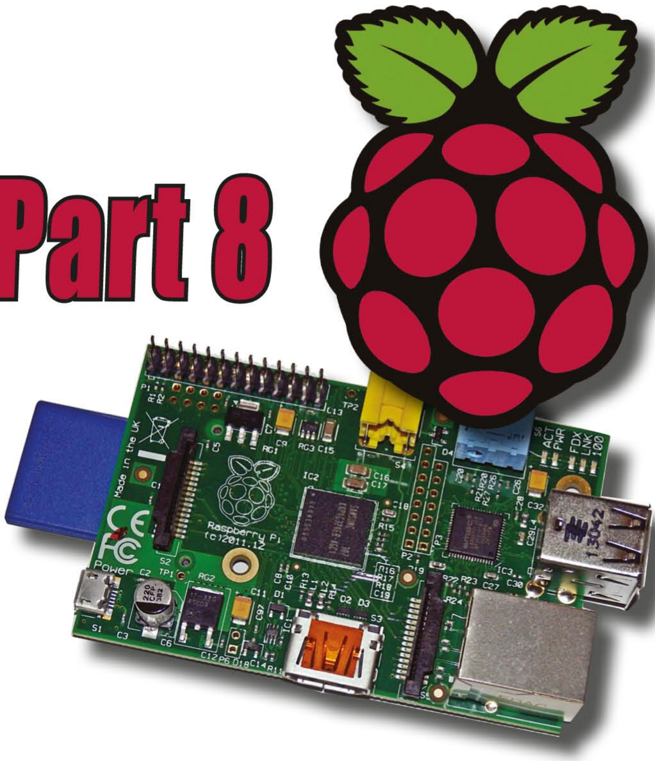
Teach-In 2014
Raspberry Pi – Part 8

by Mike and Richard Tooley



Welcome to *Teach-In 2014* with Raspberry Pi. This exciting series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Raspberry Pi, as well as computer buffs eager to explore hardware and interfacing. So, whether you are considering what to do with your Pi, or maybe have an idea for a project but don't know how to turn it into reality, our *Teach-In* series will provide you with a one-stop source of ideas and practical information.

The Raspberry Pi offers you a remarkably effective platform for developing a huge variety of projects; from operating a few lights to remotely controlling a robotic vehicle through the Internet. *Teach-In 2014* is based around a series of practical exercises with plenty of information for you to customise each project to meet your own requirements.

The Raspberry Pi is no mean performer; it can offer you very similar performance to that which you might expect from a larger and much more expensive computer system, so don't be fooled by the relatively small price tag. By shopping around you can build a very effective computer system based on a Raspberry Pi for less than £100. However, if you are looking for something more modest and just want to take advantage of the Raspberry Pi as a single-board computer for a particular control application then you can be up and running for a very reasonable outlay.

This series will teach you about:

- **Programming** – introducing you to the powerful Python programming language and allowing you to develop your programming skills
- **Hardware** – learning about the components and circuits that are used to interface microcomputers to the real world
- **Computers** – letting you get to grips with computer hardware and software and helping you understand how they work together
- **Communications** – showing you how to connect your Raspberry Pi to a network and control a remote device using Wi-Fi and the Internet.

So, what's coming up? Regular features of Teach-In 2014 with Raspberry Pi will include:

- **Pi Project** – the main topic for each part will be a project that explores a particular use or application of the Raspberry Pi in the real word. Projects will include shopping for your Pi, set up, environmental monitoring, data logging, automation and remote control.
- **Pi Class** – each of our Pi Projects will be linked to one or more specific learning aims. Examples will include methods of representing and handling data, serial versus parallel data transmission and architecture of a microprocessor system.
- **Python Quickstart** – a short feature devoted to specific programming topics, such as data types and structures, processing user input, creating graphical dialogues and buttons and importing Python modules. We will help you get up and running with Python in the shortest time!
- **Pi World** – this is where we take a look at a wide range of Raspberry Pi accessories, including breadboards, prototype cards, bus extenders and Wi-Fi adapters. We will also help you build your Raspberry Pi bookshelf with a selection of recommended books and other publications.
- **Home baking –** suggested follow-up and extension activities such as 'check this out', a simple quiz, things to try and websites to visit.
- **Special features –** an occasional 'special feature'. For example, how to laser cut your own mounting plate – with additional downloadable resources such as templates and diagrams.

What will I need?

To get the best out of our series you will, of course, need access to a Raspberry Pi. If you don't already have one, don't worry – we will be explaining what you need and why you need it (we will also be showing you how you can emulate a Raspberry Pi using a Windows PC).

This month

In this month's *Teach-In 2014*, our *Pi Class* introduces stepper motors and our *Pi Project* features the construction of a simple stepper motor controller, complete with software to drive it. Our popular *Home baking* feature shows you how to connect a camera to your Raspberry Pi and how to use it to form the basis of a complete Internet-connected webcam application.

Pi Class

In this month's *Pi Class* we shall be looking at stepper motors. Stepper motors provide an accurate means of controlling and positioning a variety of different mechanisms, both linear and rotary. Stepper motors can be easily interfaced to digital circuitry and this makes them ideal for use in a wide range of microprocessor and computer-based systems. Stepper motors are available in a variety of different types, sizes and styles; they are useful in applications that range from feeding paper into a printer to rotating a platform on a battleship.

Stepper motors

Stepper motors are a form of synchronous motor in which the magnetic field is electronically switched in order to

Fig.8.1 A typical 24V stepper motor

cause the armature to rotate to the required position and at the required speed. Stepper motors have no brushes or contacts and are thus inherently reliable.

Fig.8.1 shows a typical stepper motor, which in this case operates from a 24V DC supply. Each winding of the stepper motor has a resistance of 80Ω and requires a current of 0.3A. The motor generates a step angle of 1.8° and thus 200 steps (in the same direction) are needed to perform a full revolution.

A complete stepper motor system consists of several elements, usually combined with some form of command signal interface, as shown in Fig.8.2. The individual command signals usually appear at conventional TTL logic levels (ie, 0V to +5V) and they may be derived from conventional switches or from a microcontroller or computer that is capable of controlling a number of devices, such as other stepper motors, actuators, heaters, warning devices or displays.

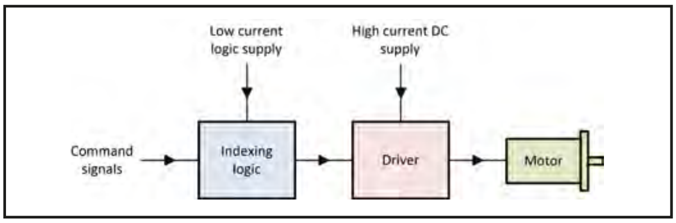


Fig.8.2. A stepper controller/driver

The indexing logic (sometimes referred to as a 'controller' or 'indexer') is a circuit that generates the required sequence of step and direction pulses in order to produce the required motion from the stepper motor. Each pulse is a logic transition, either 0-1-0 or 1-0-1. The indexing logic requires a standard logic supply (usually +5V) at a modest current (typically less than 50mA). The stepper motor, on the other hand, requires a high current (invariably more than 100mA) and thus some form of driver is required between the indexing logic output and the stepper motor coils.

An alternative arrangement is shown in Fig.8.3. This uses an integrated circuit that not only performs the control and indexing logic functions, but also contains open-collector transistor arrays, allowing the chip to be connected directly to the windings of a stepper motor. In many simple applications, the inputs to the stepper motor controller chip can take the form of just three basic command signals, STEP, DIRECTION and RESET (as indicated in Fig.8.3). The function of the basic command signals shown in Fig.8.3 are as follows:

STEP – pulse applied to this input causes the stepper motor to rotate through its fundamental step angle (eg, 1.8°) in the direction determined by the DIRECTION input

DIRECTION – logic low or high on this input determines the direction in which the stepper motor rotates, eg, logic 1 = clockwise (CW) and logic 0 = anti-clockwise (CCW)

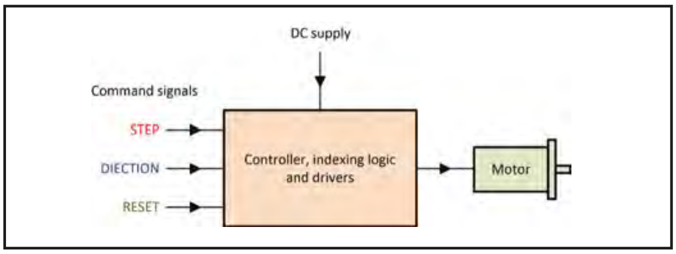


Fig.8.3. A stepper controller/driver based on a single integrated circuit

RESET – logic low or high on this input determines whether the stepper motor is operating (ie, responding to commands on its STEP and DIRECTION inputs) or is held in a non-operating state.

Types of stepper motor

There are basically three types of stepping motor: variable reluctance, permanent magnet and hybrid. The variable reluctance motor does not use a permanent magnet. Therefore, the motor rotor is free to move without constraint or detent torque. This type of construction is ideal for many small applications where there's no need for a high degree of motor torque.

The permanent magnet (PM) motor (sometimes also referred to as a 'canstack' motor) has, as its name implies, a permanent magnet rotor. It is a relatively low speed, high torque device with large step angles of either 45° or 90°. This type of motor offers very simple construction and thus low cost, which makes it an ideal choice for many small non-industrial applications.

Unlike other types of stepping motors, the rotor of the PM motor has no teeth and is designed to be magnetised at right angles to its axis. Applying current to each winding in sequence causes the rotor to move by adjusting to the changing magnetic fields. Although it operates at fairly low speed, the PM motor provides a relatively high torque.

Hybrid motors combine the best characteristics of the variable reluctance and PM motors. They are constructed with multi-toothed stator poles and a permanent magnet rotor. Standard hybrid motors have 200 rotor teeth and rotate at 1.8° step angles. Other hybrid motors are available in 0.9° and 3.6° step angle configurations. Because they exhibit high static and dynamic torque, and run at very high step rates, hybrid motors are used in a wide variety of industrial applications.

Stepper motor operation

Fig.8.4 shows the simplified arrangement of a variable reluctance stepper motor that has just six stator teeth (three pairs of poles when energised) and four rotor teeth. This motor is capable of producing a basic step angle of 30°. When two opposite stator coils (eg, A1 and A2, B1 and B2 or C1 and C2) are energised, the rotor teeth will move in order to align with the energised stator poles (minimising the reluctance along the path of the applied magnetic field). By energising the windings in a particular sequence, the stator field can be made to change so that the rotor will move to a new position following each change. Note that, unlike permanent magnet stepper motors, variable reluctance types have no residual torque to hold the rotor at a fixed position when no current is applied.

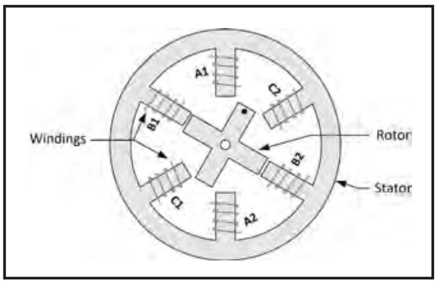


Fig.8.4. Simplified arrangement of a variable reluctance stepper motor

Fig.8.5 shows how the simple variable reluctance stepper motor can be made to turn, first through an angle of 30° anti-clockwise (ACW) and then through a further 30° ACW. The sequence of energising the motor so that it turns through a complete revolution is shown in Table 8.1 below. If the motor is to turn clockwise (CW) instead of ACW, then the required sequence is shown in Table 8.2. These sequences are generated by the indexing logic that we mentioned earlier. (Note: four complete cycles are required to turn the rotor through a complete revolution.)

Stepper motor windings

Various types of winding configuration are found in stepper motors. Stepper motors with unifilar windings (as the name implies) have only one winding per stator pole. Bifilar wound motors have two identical sets of windings on each stator pole. This type of winding configuration simplifies operation in that transferring current from one coil to another wound in the opposite direction will reverse the rotation of the motor shaft. By contrast, in a unifilar application, it is necessary to

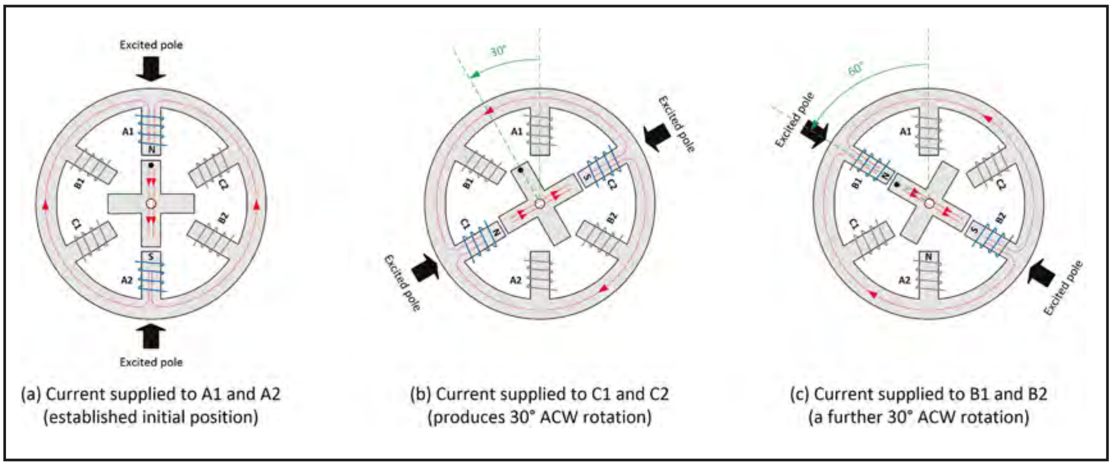


Fig.8.5. Principle of operation of the variable reluctance stepper motor shown in Fig.8.4

reverse the current in the winding in order to change direction.

Figs.8.6 and 8.7 show two possible bifilar winding arrangements. Fig.8.6 is based on centre-tapped windings, while Fig.8.7 shows a stepper motor with two sets of windings per stator pole.

It is important to note that the stepper motor driver must take into account the type of windings that are used on the stepper motor. Thus, some types of driver are unsuitable for use with some types of motor.

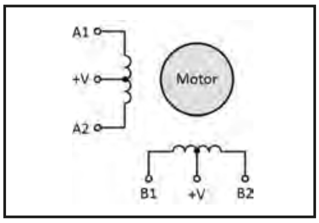


Fig.8.6. A bifilar-wound stepper motor using centre-tapped (bifilar) windings

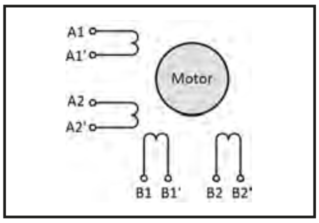


Fig.8.7. A bifilar stepper motor with two separate windings on each pole

Table 8.1 Energising sequence for one revolution of the motor in Fig.8.4 in an anti-clockwise (ACW) direction

Cycle	A1 and A2	B1 and B2	C1 and C2	Rotation ACW
1	On	Off	Off	0°
	Off	Off	On	30°
	Off	On	Off	60°
2	On	Off	Off	90°
	Off	Off	On	120°
	Off	On	Off	150°
3	On	Off	Off	180°
	Off	Off	On	210°
	Off	On	Off	240°
4	On	Off	Off	270°
	Off	Off	On	300°
	Off	On	Off	330°

Table 8.2 Energising sequence for one revolution of the motor in Fig.8.4 in a clockwise (CW) direction

Cycle	A1 and A2	B1 and B2	C1 and C2	Rotation CW
1	On	Off	Off	0°
	Off	On	Off	30°
	Off	Off	On	60°
2	On	Off	Off	90°
	Off	On	Off	120°
	Off	Off	On	150°
3	On	Off	Off	180°
	Off	On	Off	210°
	Off	Off	On	240°
4	On	Off	Off	270°
	Off	On	Off	300°
	Off	Off	On	330°

Stepping modes

Many stepper motors and their associated controllers and drivers are able to operate in different step modes, including full, half and a special 'microstep' mode. The type of step mode output is dependent on the design of the driver.

Full-step mode

Standard (hybrid) stepping motors have 200 rotor teeth, or 200 full steps per revolution of the motor shaft. Dividing the 200 steps into a full 360° rotation results in a fundamental step angle of 1.8°. Normally, full-step mode is achieved by energising both windings while reversing the current alternately. Essentially, one digital input from the driver is equivalent to one step.

Half-step mode

Half step simply means that the motor is rotating at 400 steps per revolution. In this mode, one winding is energised and then two windings are energised alternately, causing the rotor to rotate through half the fundamental angle, or 0.9°. (The same effect can be achieved by operating in full-step mode with a 400 step per revolution motor). Despite producing slightly less torque, half stepping is often a more practical solution in industrial applications where smooth rotation is essential.

Microstep mode

Microstepping is a relatively new and more sophisticated stepper motor technology that controls the current in the motor winding to a degree that further subdivides the number of positions between poles. Some controllers are capable of rotating at 1/256 of a step (per step), or over 50,000 steps per revolution.

Stepper motor controller/driver chips

In many cases, the functions of the motor controller and driver are conveniently combined into a single integrated circuit device (commonly referred to as a 'stepper motor controller'), as shown in Fig.8.8. Such a device usually has two separate supplies, one of which is the logic supply to the chip (usually +5V) and the other is at a higher voltage (often from +12V to +24V) for the motor windings. This is the arrangement that we will be using in this month's *Pi Project*.

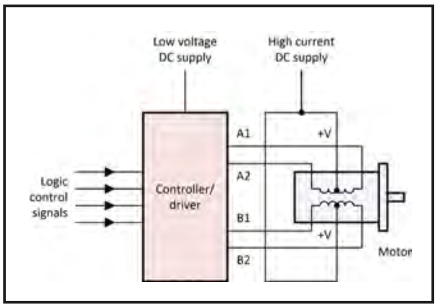


Fig.8.8. A typical controller/driver arrangement for a centre-tapped bifilar stepper motor

Last month, we described the construction of a port expander that will provide you with a further 16 programmable I/O channels. This month, we will be describing the construction of a stepper motor controller for the Raspberry Pi.

NJM2671 stepper motor controller

Our stepper motor controller makes use of a New Japan Radio Company (JRC) NJM2671 stepper motor controller. This device can be driven directly from just three of the Raspberry Pi's GPIO lines. The NJM2671 is a two-phase unipolar device, which is capable of driving motors rated at a maximum of 60V and 500mA. The chip's interface to a host controller is based on the simple STEP, DIRECTION and RESET method that we described earlier in *Pi Class*. This makes the NJM2671 extremely easy to use, with only minimal software required to control a stepper motor. The chip also incorporates simple switching between half and full-step modes.

The simplified internal arrangement of the NJM2671 is shown in Fig.8.9 and the signals are summarised in Table 8.3. The version of the NJM2671 that we shall be using has the suffix D2 and is supplied in the conventional (and easy-to-use) 16-pin plastic dual-in-line (DIL) package shown in Fig.8.10.

Operation

All of the NJM2671's inputs are compatible with standard LS-TTL logic and they all assume a high (logic 1) state in the absence of any input connection. As mentioned earlier, the NJM2671 has built-in indexing logic for controlling the current in the stepper motor windings.

When a stepping pulse (STEP) is applied, the internal phase logic sequencer goes positive on every negative edge of the STEP signal (pulse). In full-step mode, the pulse turns the stepping motor at the basic 1.8° step angle. In half-step mode, two pulses are required to turn the motor through the basic step angle. The DIR (direction) signal and HSM (half/full mode signal) are latched on the STEP negative edge and must therefore be established before the start of the negative edge. Note the 400µs setup time in the NJM2671's timing diagram shown in Fig.8.11.

The direction (DIR) signal determines the step direction. The direction of the stepping motor depends on how the NJM2671 is connected to the motor. Although DIR can be modified, this should be avoided since a misstep of one pulse increment may occur if DIR is set during a negative-edge transition (see the timing diagram in Fig.8.11).

The HSM (half-step mode) signal determines whether the stepping motor turns in either half-step or full-step mode. The NJM2671's phase logic is set to the half-step mode when HSM is taken low. When HSM is taken high, the chip operates in the normal full-step mode. Note that, although HSM can be modified during normal programmed operation, this should be avoided since a misstep of one pulse increment may occur if HSM is set during a negative-edge transition (see Fig.8.11).

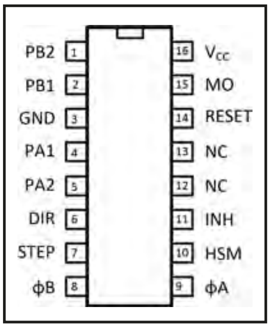


Fig.8.10. Pin connections for the NJM2671

The INH (inhibit) signal is used to disable all of the NJM2671's phase outputs. In this condition all of the output lines (PA1, PA2, PB1 and PB2) are taken high. This removes the current supplied to the stepper motor windings, releasing the motor and reducing power consumption.

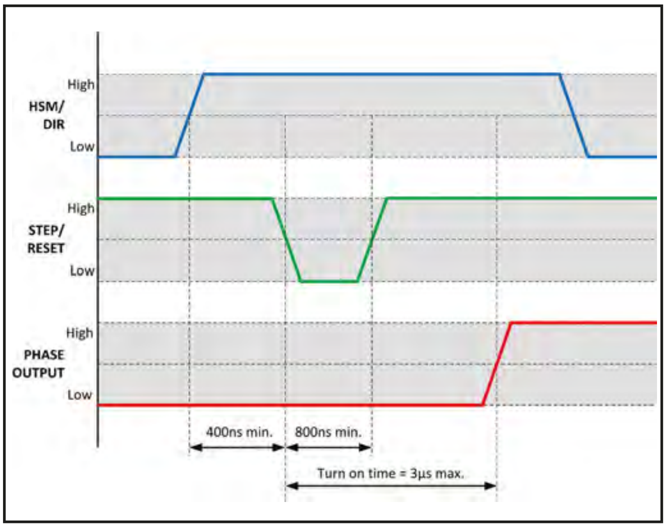


Fig.8.11. Timing diagram for the NJM2671

The two-phase stepping motor repeats the same phase output sequence when turned through an angle that is a multiple of four of the basic step, so the phase logic sequence is repeated every four pulses in the full-step mode and every eight pulses in the half-step mode.

RESET initialises the phase sequence and disconnects all of the drivers thus releasing the stepper motor and placing the circuit in standby (low-current) mode. An internal power-on reset circuit is used to reset the phase logic and turn off the phase outputs (PA1, PA2, PB1, and PB2). The starting phase logic sequence is re-initialised each time power is connected to the chip. The four outputs (PA1, PA2, PB1, PB2) control the current in the stepper motor windings and are derived from four open-collector switching transistors.

The phase-A (ΦA) and phase-B (ΦB) outputs from the sequencing logic are provided so that external circuitry is able to determine the current phase of the energising sequence. Missteps normally occur unless the switch from half-step to full-step mode is performed at the appropriate time. The ΦA and ΦB outputs are designed to enable switching between the half- and full-step modes without missteps. This should be performed when ΦA and ΦB are both at low (logic 0) level. The origin monitor (MO) signal is provided for use at the start of a phase logic sequence (or after POR or external RESET). When MO goes low (logic 0) external devices are made aware that the energising sequence is in initial status.

The output sequences produced by the NJM2671 for clockwise (CW) and anticlockwise (ACW) operation are respectively shown in Fig.8.12 and Fig.8.13.

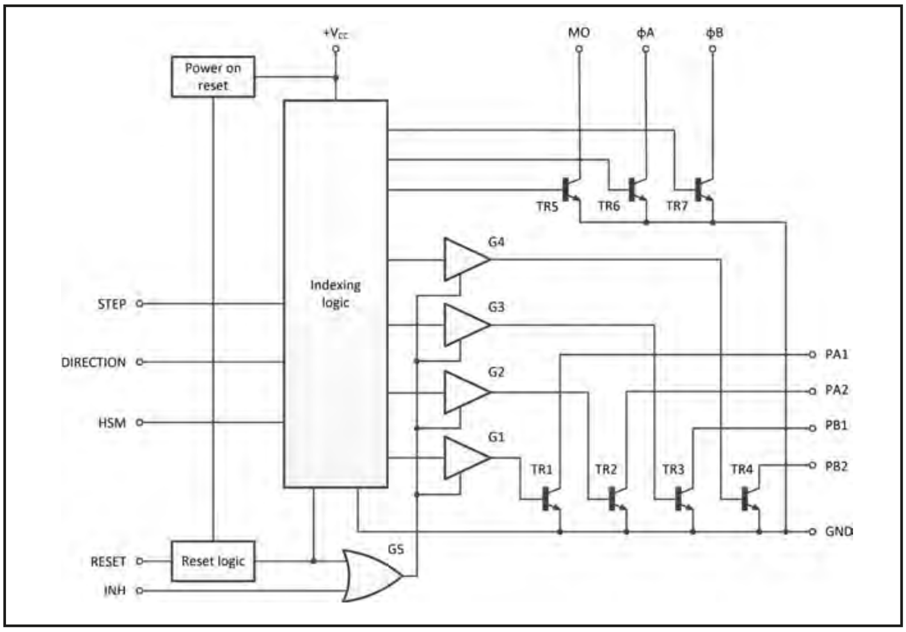


Fig.8.9. Simplified block schematic of the NJM2671

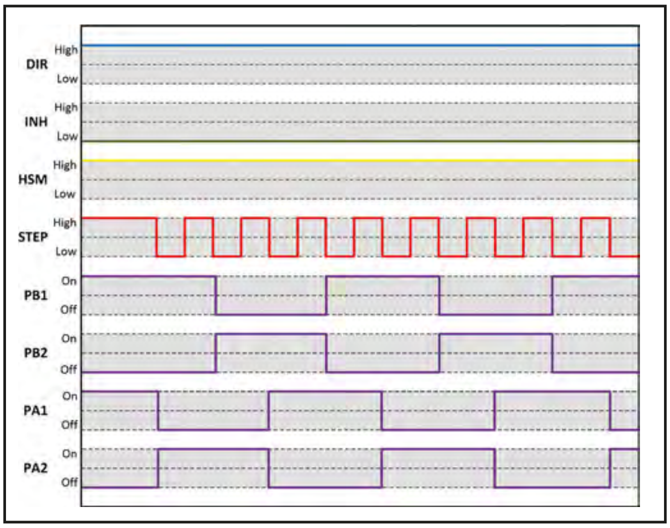


Fig.8.12. Output sequence for clockwise (CW) operation in full-step mode

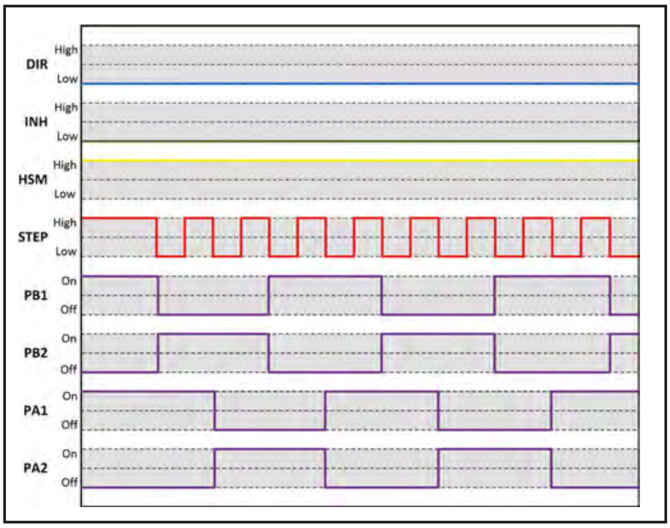


Fig.8.13. Output sequence for anti-clockwise (ACW) operation in full-step mode

Table 8.3 NJM2671 signals

Signal	Pin no.	Direction	Function
PB2	1	O	B2 phase output (note 1)
PB1	2	O	B1 phase output (note 1)
GND	3	n/a	Ground (0V)
PA1	4	O	A1 phase output (note 1)
PA2	5	O	A2 phase output (note 1)
DIR	6	I	Direction input (note 2)
STEP	7	I	Step input (note 3)
ΦB	8	O	Half-step sequence monitor for phase B
ΦA	9	O	Half-step sequence monitor for phase A
HSM	10	n/a	Ground
INH	11	I	Inhibit/standby (note 4)
NC	12	n/a	Not connected
NC	13	n/a	Not connected
RESET	14	n/a	Not connected
MO	15	O	Phase output initial status detection
VCC	16	n/a	Positive supply

Notes

1. Phase outputs are open-collector and each can sink a maximum current of 500mA
2. The motor turns clockwise (CW) when taken high and anticlockwise (ACW) when taken low
3. Motor stepping pulse input (phase logic is triggered by negative edge applied to this input)
4. All phase outputs (PA1, PA2, PB1 and PB2) go high to release the motor when this input is taken high.

Prototype stepper motor controller

The complete circuit of the stepper motor controller is shown in Fig.8.14. Three transistors, TR1 to TR3 are used to change the logic levels from the +3.3V high level on the Pi to the standard levels required by the TTL-compatible logic within the NJM2671. The connections to the Raspberry Pi are made via the GPIO connector (P1 on the Raspberry Pi). The four connections are shown in Table 8.4.

Table 8.4 GPIO connections for the stepper motor controller

GPIO pin number	GPIO signal	NJM2671 signal
11	GPIO17	STEP
12	GPIO18	DIRECTION
13	GPIO21	INH
6	Ground	GND

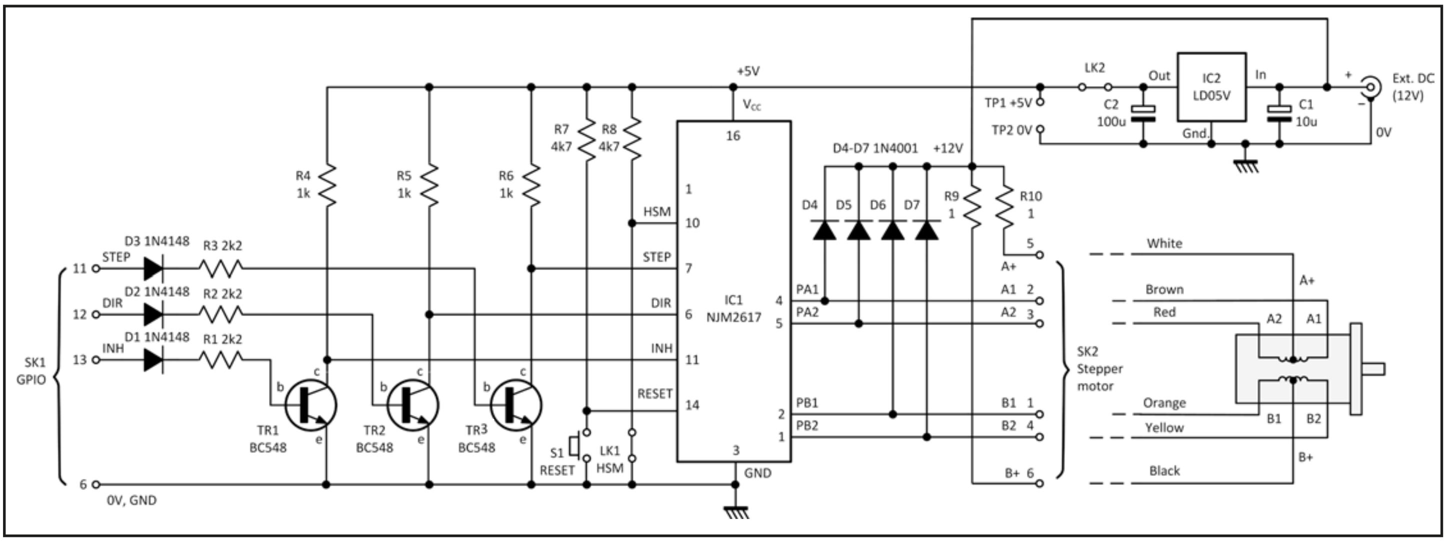


Fig.8.14. Complete circuit of the prototype stepper motor controller

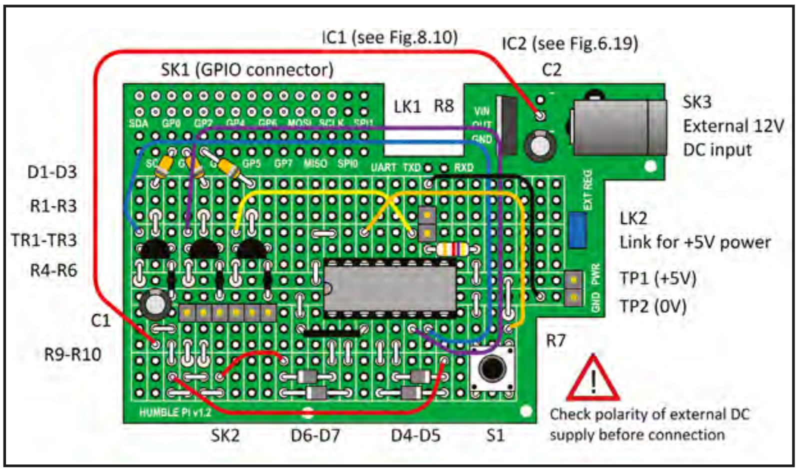


Fig.8.15. Humble Pi prototype board layout

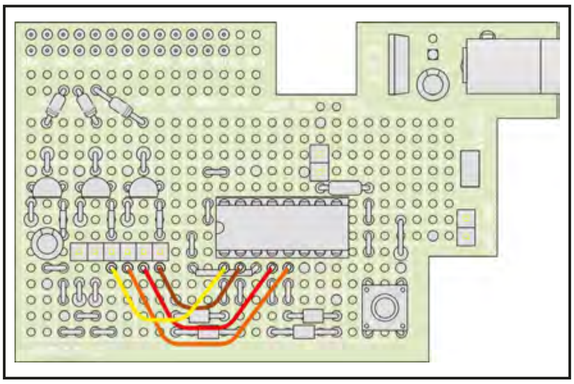


Fig.8.16. Humble Pi prototype board layout showing flying ribbon cable link to SK2

Power supplies

A 5V regulator, IC2, provides the supply for all of the NJM2671's internal logic (note that this rail does not also supply the stepper motor; a considerably higher voltage is normally required for this). An external (unregulated) supply of nominally 9V at up to 500mA provides the input to IC2. For applications that only have modest current requirements (up to 50mA, or so) the regulator is not required and IC2 can derive its positive supply from the Raspberry Pi (pin-1 on P1). Despite this, and to ensure maximum protection for your Pi (avoiding the risk of inadvertent supply misconnection) we would strongly recommend the use of a suitably rated external power supply and an additional voltage regulator for all I/O applications. For test purposes, test points TP1 and TP2 can be fitted in order to provide access to the +5V line and, if necessary, LK2 can be removed in order to isolate the NJM2671 from its local +5V supply.

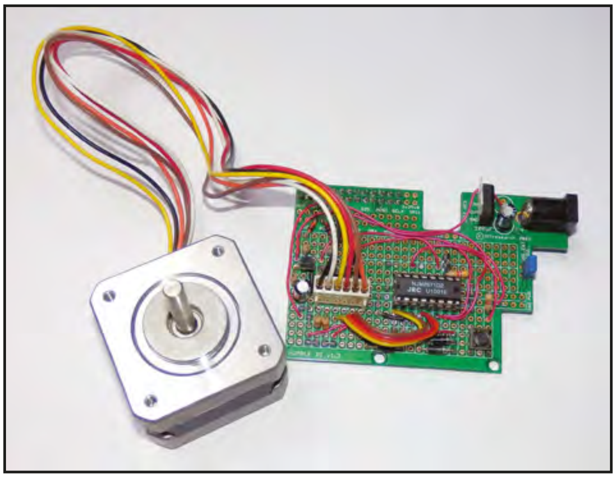


Fig.8.17. The completed Humble Pi prototype board and stepper motor

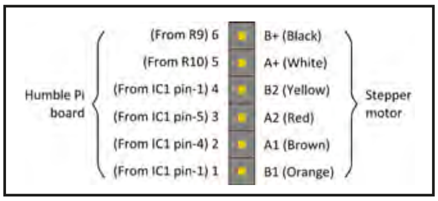


Fig.8.18. Pin connections for the stepper motor connector, SK1

The Humble Pi prototyping board

We built our prototype stepper motor controller using a Humble Pi prototyping board and the wiring layout shown in Fig.8.15 and 8.16. The Humble Pi prototyping board should be fitted with the 26-way connector (SK1) supplied with the Humble Pi. This connector mates with the male connector (P1) on the Raspberry Pi and it ensures that the Humble Pi board sits neatly piggy-back style above the Raspberry Pi. The completed prototype board connected to a stepper motor is shown in Fig.8.17.

As pointed out last month, there have been some recent changes to the pin labelling convention used on Humble Pi prototyping boards. The latest Version 1.3 boards use pin labelling based on the Broadcom (BCM) chip signals, while earlier versions were based on the earlier Raspberry Pi GPIO pin convention. These changes were described in last month's *Teach-In*.

The pin connections for the stepper motor connector (SK2) are shown in Fig.8.18. The power supply for the NJM2671 (and other board-mounted components) is based on the kit supplied as an optional extra for use with the Humble Pi prototyping board. The kit consists of a low-dropout voltage regulator (LD33V, LD50V, or equivalent), two capacitors, and a standard DC power connector. Note that, for this application, you will require a 5V regulator (LD50V) and not a 3.3V regulator (LD33V). The four additional power supply components can be quickly and easily fitted to the Humble Pi prototype board (see Fig.8.15 and 8.17). Pin connections to the 5.0V regulator (IC2) are shown in Fig.8.19.

The stepper motor power supply will need to be chosen in order to meet the requirements of the individual stepper motor used. We tested our stepper motor controller with a low-cost Y29 stepper motor from Rapid Electronics (part number 37-0506) and a power supply rated at 12V, 1A. The characteristics of this motor are summarised in Table 8.5 and the wiring diagram is shown in Fig.8.20. The stepper motor configuration and connections are shown in Fig.8.20.

Table 8.5 Y29 stepper motor characteristics

Parameter	Specification
Step angle	1.8°
Step angle accuracy	5%
Phase current	160mA
Phase resistance	75Ω
Phase inductance	60mH
Holding toque	9Ncm
Detent torque	1.5Ncm
Rotor inertia	28g.cm^2
Mass	0.22kg

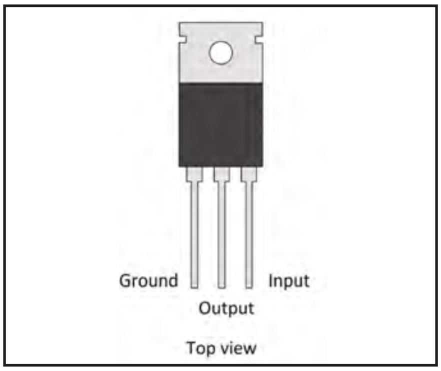


Fig.8.19. IC2 pin connections

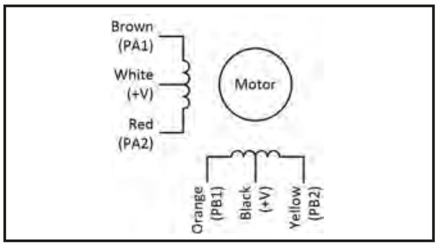


Fig.8.20. Stepper motor configuration and connections

Testing the stepper motor controller

The stepper motor controller can be easily tested using some simple Python code:

```
# Stepper motor test routine for Python 3
# One quarter revolution CW in 10s followed
# by one quarter revolution ACW in 10s
# Motor left in standby mode

# Import the required libraries
import RPi.GPIO as GPIO
import time

# Define pin numbering convention
GPIO.setmode(GPIO.BOARD)
# Set up pins 11, 12 and 13 as outputs
GPIO.setup(11,GPIO.OUT) # STEP
GPIO.setup(12,GPIO.OUT) # DIRECTION
GPIO.setup(13,GPIO.OUT) # INH

# Take INH high to energise the motor
GPIO.output(13,1)

# Get ready to start
print('Motor starting in 4 seconds ...')
time.sleep(4)

# Quarter revolution ACW
GPIO.output(12,0) # Direction = CW
n = 0
while n < 50:
   GPIO.output(11,1)
   time.sleep(0.1)
   GPIO.output(11,0)
   time.sleep(0.1)
   n = n + 1

# Quarter revolution CW
GPIO.output(12,1) # Direction = ACW
n = 0
while n < 50:
   GPIO.output(11,1)
   time.sleep(0.1)
   GPIO.output(11,0)
   time.sleep(0.1)
   n = n + 1

# Take INH low to release the motor
# and place the NJM2671 in standy
GPIO.output(13,0)

# Finally clean up the GPIO
GPIO.cleanup()
```

Finally, here's a complete example of an application that uses Tkinter (see *Teach-In 2014*, Part 4) to control a stepper motor from the simple graphical user interface shown in Fig.8.21). The user interface has three radio buttons labelled Release, Clockwise and Anticlockwise. Only one of these can be selected at any time. The user selects one of these conditions, after which clicking on the GO button will produce the required action (in this case one complete revolution of the motor in either direction). A Release option is provided so that the motor can be placed in a standby low-power consumption state and, if necessary, it can then also be turned by hand. The software (written in Python 3.x) can easily be extended in order to permit a wider variety of options. In a future *Teach-In 2014* we will have more on techniques that can be used for constructing more complex and powerful user interfaces.

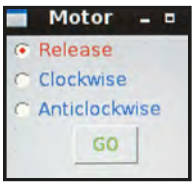


Fig.8.21. The simple radio button user interface

```
# Stepper motor application for Python 3
# Control via radio button dialogue
# Uses full step mode (no link in place)
# Import the required libraries
import RPi.GPIO as GPIO
import time
from tkinter import *

# Define the pin numbering convention
GPIO.setmode(GPIO.BOARD)
# Set up pins 11, 12 and 13 as outputs
GPIO.setup(11,GPIO.OUT) # STEP
GPIO.setup(12,GPIO.OUT) # DIRECTION
GPIO.setup(13,GPIO.OUT) # INH

def stop(): # Release the motor to standby
   GPIO.output(13,0)
   time.sleep(1)

def cw(): # Full revolution ACW
   # Take INH high to energise the motor
   GPIO.output(13,1)
   time.sleep(1)
   GPIO.output(12,0) # Direction = CW
   n = 0
   while n < 200:
      GPIO.output(11,1)
      time.sleep(0.01)
      GPIO.output(11,0)
      time.sleep(0.01)
      n = n + 1

def acw(): # Full revolution CW
   # Take INH high to energise the motor
   GPIO.output(13,1)
   time.sleep(1)
   GPIO.output(12,1) # Direction = ACW
   n = 0
   while n < 200:
      GPIO.output(11,1)
      time.sleep(0.01)
      GPIO.output(11,0)
      time.sleep(0.01)
      n = n + 1

def sel():
   option = str(var.get())
   if option == '1':
      stop()
   if option == '2':
      cw()
   if option == '3':
      acw()

# Dialogue window with radio buttons
root = Tk()
root.title('Motor')
root.minsize(140,100)
var = IntVar()
# First radio button
R1 = Radiobutton(root, text='Release', fg='red', variable=var, value=1)
R1.pack(anchor=W)
# Second radio button
R2 = Radiobutton(root, text='Clockwise', fg='blue', variable=var, value=2)
R2.pack(anchor=W)
# Third radio button
R3 = Radiobutton(root, text='Anticlockwise', fg='blue', variable=var, value=3)
R3.pack(anchor=W)
# Go button
G = Button(root, text='GO', fg='green', command=sel)
G.pack()
root.mainloop()
GPIO.cleanup()
```

Radio buttons and check boxes

A radio button is a device used in a graphical user interface (GUI) that allows users to select one of a number of mutually exclusive options. Radio buttons are usually arranged in vertical groups of two, three, four, or more circular buttons with the currently selected button filled in. Note that only one radio button can be activated at a time, so when one button is selected any previous selection is cancelled. This needs to be contrasted with check boxes where one or more options can be selected at the same time. Check boxes usually appear as square boxes, which have ticks inserted in them when selected. Fig.8.22 shows an example of a dialogue box written using Python and Tkinter (displayed on a Windows-based PC). The dialogue box is used to control one channel of an oscilloscope application and it allows users to select either AC or DC inputs via radio buttons and any of three options for the display using check boxes.

Fig.8.22 An example of radio buttons and check boxes

Home Baking

Last month, we explained how the Raspberry Pi could be used to act as a web server. This month, we are going to look at one of the Pi's most popular accessories; the Pi camera. There is a huge variety of potential applications for the Pi camera and this device opens up even more options for your exciting home-baked Pi projects.

The Pi camera is really quite an impressive piece of kit, especially considering its modest price tag of around £20. The camera itself is fixed focus with a maximum still resolution of five megapixels (2592 × 1944). Video recording is possible up to 1080p at 30 frames per second and up to 90 frames per second at lower resolutions. Barely bigger than a postage stamp, the camera module measures just 20 × 25mm, and is supported by both A and B Pi versions.

The camera is available in two flavours; the standard model and the 'NoIR' model. The NoIR model has the infrared filter removed. An infrared filter is normally included in a camera lens as photo sensors are sensitive to infrared light as well as visible light. Normally, we want our photos/videos to looks like they do 'though our own eyes', which are not sensitive to light in the infrared part of the spectrum. Therefore, these filters stop the infrared light from affecting the image sensor. However, there are times when the infrared sensitivity is very desirable, for example, in low light/night vision or for infrared nature photography. We will be exploring this aspect in the next part of our *Teach-In 2014* series.

Finally, it's worth noting that the camera is supplied as a bare PCB not a boxed unit – therefore it is well worth investing in some sort of mount/holder for your Pi camera at the time of purchase. This will not only protect the camera, but allow you to aim/position it more precisely.

Installing your Pi camera

Installing the hardware is straight forward if a little fiddly. Do take your time with this operation to avoid damaging any fragile elements. The manufacturers also specifically note the static sensitivity of the camera and you should therefore use appropriate grounding equipment if available, or at the very least discharge any charge on yourself before handing; for example by touching a grounded object such as a tap, metal pipe or radiator. Before installing, shut down your Pi appropriately and disconnect your power supply.

The Pi camera is supplied with a short length (approximately 15cm) of 15-way flexible flat ribbon cable (see Fig.8.24). This cable must be attached to the Raspberry Pi using the Pi's dedicated camera connector shown in Fig.8.25. To attach the cable, first release the brown 'collar' by carefully lifting each side with either a fingernail or small flat-head screwdriver (see the two red arrows shown in Fig.8.25). Take great care not to use excessive force, which could completely remove the collar or damage the fragile clasps. Next, insert the flex cable with the silver connections facing towards the Ethernet port. The cable should insert freely and align perpendicular to the board. You should not need to force the cable. Ensure that the cable is fully inserted then hold in place while pushing the collar back down to securely clamp the cable in position (see Fig.8.26). Take care not to overly bend the flex cable as this can be fractured. It is also worth noting that the Pi camera board is double sided, with many components mounted on the rear of the PCB (see Fig.8.27). Because of this, you should ensure that the board is kept well away from the exposed components, connectors and grounded areas of the Raspberry Pi. The use of an insulated mounting cradle or an off-the-shelf Pi camera enclosure is highly recommended.

Once the hardware has been installed it needs to be enabled. To achieve this, boot up your Pi then open a terminal window and issue the following commands to update your system and enter the configuration screen:

```
sudo apt-get update
sudo apt-get dist-upgrade
```

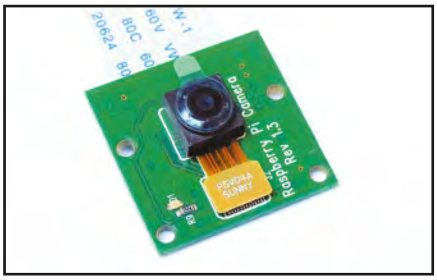


Fig.8.23. The Pi Camera straight out of its anti-static packaging

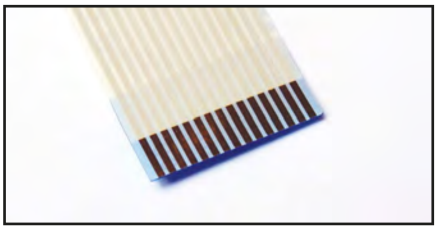


Fig.8.24. The ribbon cable from the Pi Camera (note the blue insulated reinforcement is on the rear side of the plated edge connectors)

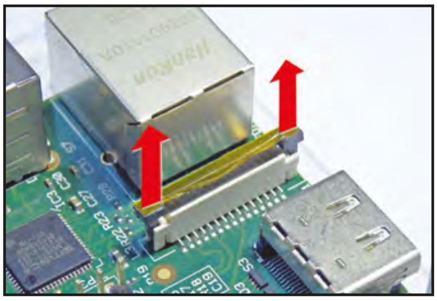


Fig.8.25. The Raspberry Pi's dedicated camera connector. The red arrows show the direction in which the connector is released ready for insertion of the ribbon cable

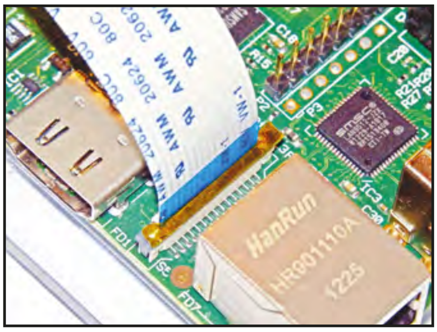


Fig.8.26. The Pi Camera hardware installed (note the orientation of the blue reinforcement)

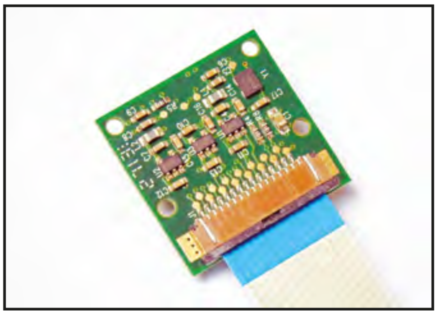


Fig.8.27 Exposed components fitted to the rear of the Pi Camera board

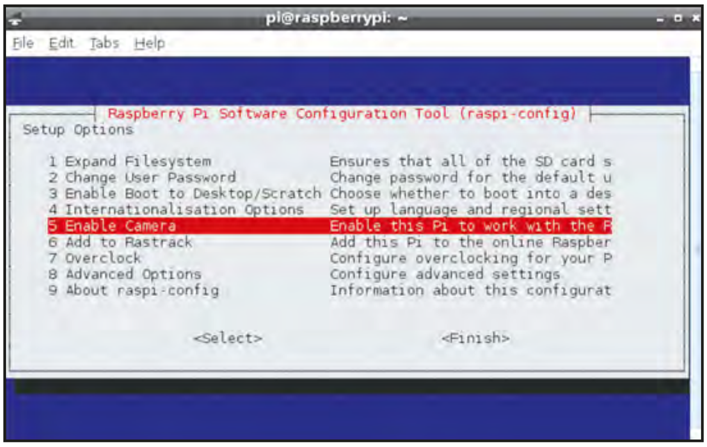


Fig.8.28. Enabling the Pi camera in `raspi-config`

Note that the upgrade can take some considerable time (particularly if your system hasn't been upgraded for a while).

Next, you need to load the now familiar Rasperry Pi configuration utility using:

`sudo raspi-config`

Scroll down to 'Camera' then select 'enable' and then reboot the system. Your Pi camera should now be ready to go.

Using your Pi camera

There are two command line camera utilities built-in to Raspbian as standard (although there are many third-party camera supporting applications available). `raspistill` is used to capture still images, while `raspivid` allows you to capture video. Both commands are actually really powerful and there are loads of options to choose from depending on what you want to achieve; far too many for us to describe all of them here. For example, you are able to manually configure settings such as the ISO, exposure and colour balance, as well as applying various filters, enhancements and effects. Full documentation for both `rasspistill` and `raspivid` is available from the Raspberry Pi Foundation website at: **www.raspberrypi.org/camera** (then follow the link for extended documentation). Alternatively run `raspivid -?` or `raspistill -?` to see all available options. By default, these features are setup automatically for taking 'normal' shots. Hence, taking pictures or video is really straightforward; for example, to simply take a photo use the command:

```
raspistill -o myphoto.jpg
```

This will immediately take a photo at full resolution (5MP) using the default settings and save it in jpeg format with the filename `myphoto.jpg` in the home directory. You can view your photos using the system photo viewer by locating and double clicking the file from within file manager.

If you prefer the opportunity to setup your photo (or to get into your cheesiest pose) with a preview first you can add the timeout `–t` option, along with the required delay in milliseconds. For example for a five-second preview with a photo taken at the end use:

```
raspistill -o mphoto.jpg –t 5000
```

Taking video is equally easy. The following will take a ten-second video in high quality h264 format, saving it as `myvideo.h264`:

```
raspivid -o myvideo.h264 -t 10000
```

Table 8.6 Popular options for `raspistill` and `raspivid`

Option	Still	Vid	Name	Description
`-o [filename]`	x	x	Output	Outputs to a file. Without this no file will be saved.
`-t [time period in ms]`	x	x	Timeout	Sets the amount of time before a shot with `raspistill` or the video length in `raspivideo`
`-tl [period in ms]`	x		Timelapse	Takes a picture every period specified
Size and quality				
`- h [height in pixels]`	x	x	Height	Sets the height of the captured photo/video
`-w [width in pixels]`	x	x	Width	Sets the height of the captured photo/video
`-q [percentage]`	x		Quality	Sets the compression quality (`0` to `100`)
`-e [jpg/png/gif/png]`	x		Encoding	Sets the encoding format
`-fps [framerate]`		x	Frame rate	Sets the video frame rate
`-b [bitrate in bits/s]`		x	Bitrate	Sets the video bitrate in bits/second
Preview				
`-p [x,y,w,h]`	x	x	Preview	Sets the preview position (`x,y`) and the size (`w,h`)
`-f`	x	x	Full screen	Full screen previewt
`-n`	x	x	No preview	No preview
Image				
`-sh [percentage]`	x	x	Sharpness	Sets sharpness (`-100` to `100`)
`-co [percentage]`	x	x	Contrast	Sets contrast (`-100` to `100`)
`-br [percentage]`	x	x	Brightness	Set brightness (`0` to `100`)
`-sa [percentage]`	x	x	Saturation	Set saturation (`-100` to `100`)
`-ISO [ISO]`	x	x	ISO	Set ISO
`-vs`	x	x	Video stabilisation	Enable video stabilisation
`-ex [mode]`	x	x	Exposure	Set exposure mode*
`-awb [mode]`	x	x	White balance	Set white balance mode*
`-ifx [effect]`	x	x	Image effect	Apply image effect*
`-cfx [effect]`	x	x	Colour effect	Apply colour effect*
`-mm [mode]`	x	x	Metering mode	Set metering mode*
`-rot [rotation in degrees]`	x	x	Rotation	Set image rotation (`0` to `359`)
`-hf`	x	x	Horizontal Flip	Flip image horizontally
`-vf`	x	x	Vertical flip	Flip image vertically

*refer to the full documentation for the available modes/effects/ arguments.

Note that the timeout option is used here to specify the length of the video clip (again in milliseconds).

You can run a built-in demo option (`-d`) so that you can see some of the extended options available. To launch a three-minute demo that cycles through the various options run:

```
raspivid -t 180000 -d
```

One particularly popular feature is the ability to take time lapse photos, whereby a series of photo are taken periodically over a period of time. The output file may either be overwritten or the filenames serialised. For example:

```
 raspistill -o timelapse%04d.jpg -t 3600000
-tl 10000
```

This will take a photo every ten seconds (10,000ms) for one hour (3,600,000ms). The result will be a series of 360 images in the format `timelapse0001.jpg`, `timelapse0002.jpg` etc. The %04d specifies that a four digit decimal number should be appended to the filename. Without this timelapse.jpg would be overwritten each time (which could be desirable as we'll see in our webcam project a little later). We've provided an overview of some of the most popular options for `raspistill` and `raspivid` in Table 8.6.

Using your Pi camera as a webcam

In last month's edition of *Teach-In 2014*, we described how to set up your Pi as a webserver using Apache and PHP. This month, we are going to look at a simple way to use Pi camera as a webcam to broadcast images world-wide through your web server. This article assumes that you have successfully followed last month's *Teach-In 2014* and/or have a working web server setup on your Pi.

There are plenty of examples of where being able to see what's going on around your Pi remotely could be really useful. Whether it is to monitor your home remotely for security, to check what the weather's like when you're away from home, to view the goings-on in a bird or animal nest, or to provide real-time images from a remotely-operated vehicle, this article will give you the basics to get you started. There are two main steps to achieve this, as we will describe below. The first step is to set up the Pi camera to take periodic still images and store them where they are accessible over the Internet. This is simple to achieve using the `raspistill` command:

```
sudo raspistill -n -o /var/www/webcam.jpg -w
320 -h 240 -q 50 -t 0 -tl 5000
```

This will take a still image every five seconds at a resolution of 320 × 240 and save it with the filename `webcam.jpg` in our web server's root folder at: `/var/www/` with no preview. The command must be issued as a super user in order to achieve access to the web root folder. Therefore, you may be asked to enter super user credentials upon execution. Note that we have chosen a modest resolution and have used a low quality compression of 50%. This will help keep the file size down (typically around 60Kb) to keep bandwidth down and allow for the often slow upload speed of home Internet connections.

Fig.8.29 Webroot folder showing webcam.jpg and index.html files

You'll need to run this command to start the process of periodic captures. Note that our timeout (`-t`) option is set to 0. This will mean that the script will run indefinitely until terminated or the Pi is shutdown/rebooted. Once you have issued the command in a terminal window you should leave this window open (or minimised) so that it can run in the background. Alternatively, you could issue the command using `nohup` (or 'no hang-up') which will instruct the program to run in the background without requiring the terminal session to remain open as below. Note that you are not then able to easily terminate photo taking.

```
nohup sudo raspistill -n -o /var/www/webcam.jpg -w 320
-h 240 -q 50 -t 0 -tl 5000
```

Next, we need to write a web page to display the images that we've saved. Last month, we explained that the default document (the page that is loaded when a user visits our site if no specific web page is requested) is `index.html`. We also saw that Apache creates an `index.html` file when it installs with an 'it works!' message (we used this to check that the installation completed successfully).

We're going to edit this file to include our webcam image. To do this, browse to: `/var/www/` in file manager, open the folder as root by clicking Tools > Open Current Folder as Root from the top menu. Now right-click the index.html file and select Leafpad in order to open the file in the Leafpad text editor. Edit the file to match the code below before saving.

```
<html>
<head>
<script type="text/javascript">
        <!--
        function WebcamRefresh()
        {
         var timestamp = new Date().getTime();
             document.getElementById("webcam").src  =
"webcam.jpg?" + timestamp;
        setTimeout("WebcamRefresh();", 5000);
        }
        onload = WebcamRefresh;
         -->
</script>
</head>
<body>
     <p><h1>Pi Webcam</h1><hr/></p>
     <p><h3>Welcome to my live Pi webcam page!</h3></p>
     <p>The webcam image will automatically refresh
every 5 seconds...</p>
     <p><img id="webcam"src="webcam.jpg" ></img></p>
</body>
</html>
```

We won't go into too much detail about authoring HTML code here. Our example is a very simple page used to display the image with some client-side JavaScript used to refresh it. If you have some previous experience of web design and HTML you'll be at home here and can get to work customising the page to your requirements. If you're new to this sort of thing, then why not do some Internet research to help you make your webcam page more interesting? Just do a search along the lines of: 'basic HTML code'.

The really clever bit on this page is the JavaScript within the `<script>` tags at the top. This will refresh the image on the page (not the whole page itself) every five seconds and therefore viewers will receive a periodically updated feed from the webcam. To give you a little more technical description; the webpage contains an image placeholder named 'webcam'. Our JavaScript function (called `WebcamRefresh()`) is set to start when the document loads, then starts itself again every 5000 milliseconds (ie, five seconds). Each time the script generates a variable called `timestamp` which consists of the current date/time, so it is always different. It then changes the webcam image source to `webcam.jpg` and appends a question mark and the timestamp to the filename. This makes browsers think that the image is new and needs to be reloaded. Consequently, it will then load the latest version of the file that has been captured by our `raspistill` script. Without the timestamp, browsers would think that they have already downloaded or cached the file previously and would therefore not re-fetch the updated image.

Fig.8.30 Webroot folder showing webcam.jpg and index.html files

Once you are happy with your index.htm file we can go ahead and test our webcam. This can be done either on the Pi itself by visiting `http://127.0.0.1` in a web browser, from within your local network (access from another network device replacing `127.0.0.1` with your Pi's network IP address) or externally via your dynamic DNS address as per your setup from last month's *Teach-In 2014*. If all has gone well, you should see a page similar to our example shown in Fig.8.30 with a periodically updated still image.

Depending on your requirements and/or bandwidth you may wish to alter the image size/quality or increase the frequency of update. Remember that you will need to update the JavaScript in the HTML code, as well as using an amended `raspistill` command. There will, of course, be a limit to how fast images can be taken, processed and transferred, so this method is not really intended for moving images (if this is your requirement, investigate video streaming instead).

As with all of our *Home Baking* features, it's now over to you to tweak, customise and extend what we've shown you here. So now's the time to get creative with photo and video using your Pi camera!

In next month's Teach-In with Raspberry Pi

In next month's *Teach-In 2014*, our Pi Project features the construction of an infra-red lighting source, while *Home Baking* introduces the Pi's NoIR camera. These two projects can provide you with the basis for an excellent night-vision system for your Raspberry Pi. *Python Quickstart* will show you how you can write HTML files and render them in a web browser from within your Python code. For good measure, *Pi World* delves into analogue and digital I/O using the popular and versatile Custard Pi 2.

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Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Component discussion

WHEN building electronic projects we tend to use the same few types of component over and over again. Most projects require a number of resistors, capacitors and integrated circuits. A few diodes and transistors will sometimes be needed, and there will usually be some controls that utilise variable resistors (potentiometers) and switches. Probably, most projects require one or more components that are less mundane than these, and some of these less common components are highly specialised in nature. These really fall outside the scope of this article, but we will consider some of the components that are used relatively infrequently, but are still of a more general nature.

A switch in time

There are several types of semiconductor that do not fall into the normal transistor, diode, and integrated circuit categories. Some of these are little used in modern electronics, or are now obsolete. The thyristor, which is also known as a silicon-controlled rectifier (SCR) is one that is still ‘alive and kicking’. It is a three-terminal device like a transistor, but it is a switching device rather than an amplifying type. There are drawbacks and advantages compared to alternative types of switching component, and the main advantage is their fast operation. They can typically switch on in less than a microsecond.

A thyristor is made from four layers of silicon, which compares to three for a transistor and two for a diode or rectifier. Like a diode or rectifier, two of the terminals are called the anode (a) and cathode (k). However, there is normally no path of conduction between these two terminals, even if the applied voltage is of the correct polarity. A thyristor can be switched on by applying a small current to its third terminal, which is called the gate. The device operates much like two silicon diodes in series, giving about twice the normal voltage drop through the component in the forward direction. In other words, about one volt or so is lost through the device when it is in the ‘on’ state.

A turn off

As a switching device, a thyristor has a serious flaw, which is simply that once switched on it latches in that state, and it cannot be turned off by removing the gate signal. It only switches off when the current flow between the anode and cathode terminals drops to a very low level. This is less of a drawback with another semiconductor switching device called a ‘triac’. A thyristor is only suitable for controlling DC loads, but a triac can handle AC loads.

The triac equivalents of a thyristor’s cathode and anode are called MT1 and MT2 (mains terminals 1 and 2) respectively. They are alternatively called A1 and A2 respectively. The third terminal, as before, is the gate. A triac does not switch off when the gate signal is removed, but the current flowing through the device falls to zero at the end of each half cycle, and this does cause it to switch off. Unlike a thyristor, a triac can therefore provide on/off switching via its gate signal provided it is used with an AC load.

Triacs are sometimes used in power controller applications in conjunction with a two-terminal triggering device called a ‘diac’. These are usually contained in diode-style encapsulations, which could give the impression that they have to be connected the right way around. They are in fact bidirectional, and can be connected either way around.

Triacs and thyristors look much like transistors (Fig.1). The low-current types have the usual transistor-style encapsulations, and the higher-current types look like power transistors. It used to be the norm for triacs and thyristors to be listed in component catalogues in terms of maximum voltage and current ratings, but these days they are usually listed using normal semiconductor style type numbers. Some require much higher trigger currents than others, and some triacs have a built-in diac. It is not just the maximum current and voltage ratings that are of importance, and it is not advisable to use substitutes unless you are sure that they are suitable replacements in all respects.

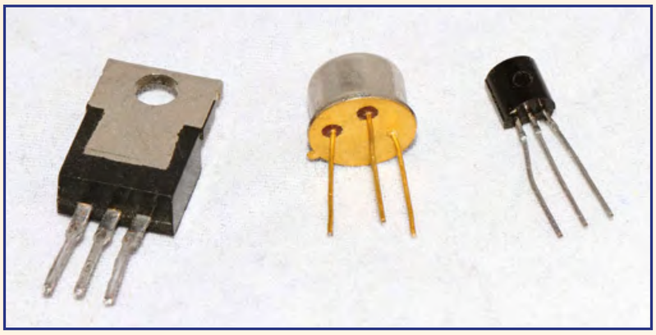


Fig.1. Transistors, triacs, or thyristors? All are three terminal devices, and use the same types of encapsulation. These are thyristors

7-segmented

It is possible to buy light-emitting diodes (LEDs) in a wide variety of shapes, colours, and sizes. There are also LED displays, and although these have to some extent been usurped by the liquid crystal variety, they are still in use today. There are two basic types of LED display, which are the bargraph and 7-segment types. A simple bargraph display typically has a column of five or ten rectangular LEDs, which can indicate six or eleven different levels. A display of this type is used for something like a temperature or fuel gauge, rather than where precise measurements are required. Modern bargraph displays are not necessarily in the form of a column of LEDs, and they can be arcs or circles for example. I suppose it is not essential to use a readymade bargraph display, and there is plenty of scope for 'doing your own thing' with some ordinary LEDs.

7-segment displays are used for the familiar numeric displays, where the segments are used in a figure-of-eight arrangement. The 7-segment LED name is perhaps not entirely apt, since most of these components include either a left or right hand decimal point, and therefore have eight LEDs. The seven main segments are identified by letters from 'A' to 'G', as in Fig.2. Bargraph displays normally have the terminals of each LED individually available on separate pins. With 7-segment displays, it is normal for a common pin to be used for all the anode terminals, or all the cathodes. Using a common-anode display instead of a common cathode type, or vice versa, will not work. The LEDs with be fed with a voltage of the wrong polarity and will not light up.

As with many components these days, it is not just the electrical characteristics of displays that are important. They are manufactured in a wide range of sizes and encapsulations, as well as in single and multiple versions. This makes it important to obtain precisely the required component if it is to fit a custom printed circuit board.

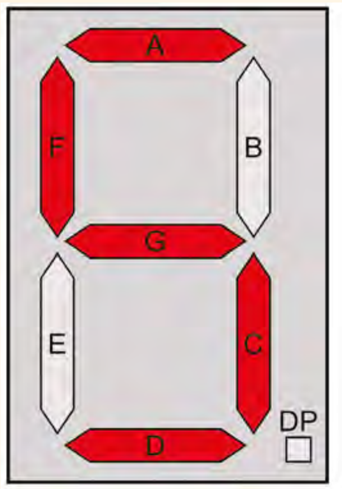


Fig.2. The segments of a 7-segment display are identified by letters from A to G. Most of these components can display a decimal point, and therefore have eight LEDs

Seeing the light

A photo-resistor (Fig.3 – left) is a special type of resistor which, as its name implies, is sensitive to light. In bright conditions the resistance is relatively low, and is typically a few hundred ohms or less. In darkness, the resistance is usual a megohm or more. Photo-resistors are relatively slow in operation, and can take a second to respond to large reductions in light level. They are generally used in simple applications rather than ones that require high-speed operation or precise measurements to be made. These components are known by other names, such as light-dependent resistors (LDRs), cadmium sulphide cells, and CdS cells.

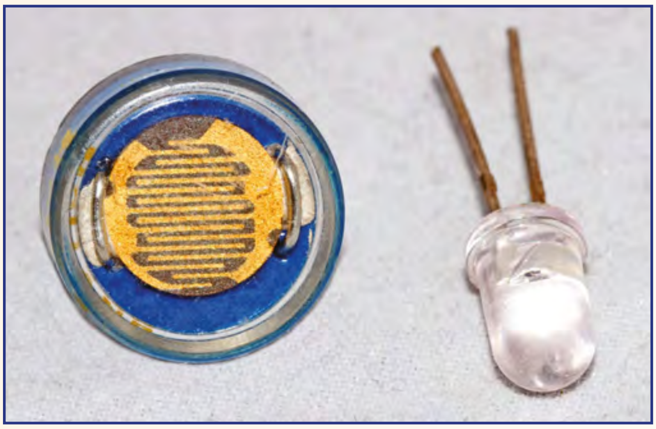


Fig.3. The zigzag light sensitive track of the light-dependent resistor (LDR) on the left is clearly visible. The LED-like component on the right is actually a photo-transistor that has no base lead

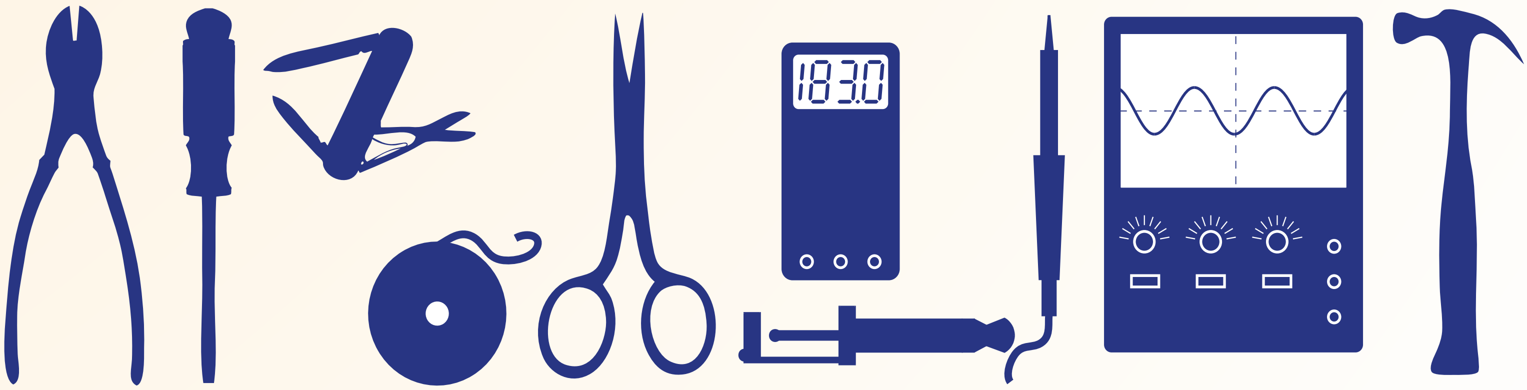
Although they are not semiconductor components, photo-resistors are usually given semiconductor-style part numbers. Because these components tend to have broadly similar characteristics, it is possible that using the wrong type will still produce a fully functioning gadget. However, and as always with this type of thing, it is advisable to use only the specified component unless you are sure that you know what you are doing.

Diodes and transistors are available in light-sensitive 'photo' versions. These are not really specially developed light-sensitive components, since sensitivity to light is a normal trait of semiconductors. They are basically just ordinary diodes and transistors that are housed in transparent encapsulations instead of the normal opaque types. The case often includes a built-in lens that improves sensitivity, but also makes the component more directional. With some components, the angle of view is just a few degrees.

Photo-transistors mostly have all three terminals available, but a few lack a leadout wire for the base connection. In many practical applications it is only the leakage current between the collector and emitter terminals that is of interest. This increases roughly in proportion to the received light level. The base terminal is often left unconnected, and it is for this reason that the base leadout wire is sometimes absent. Modern photo-diodes often look much like LEDs, as do many of the two terminal photo-transistors (Fig.3 – right).

Crystal clear

Crystals used to be used in radio communications equipment and little else. They gained a new lease of life in the digital revolution, and they are now used in watches, computers, cameras, and just about anything else that has a



digital circuit. The ‘crystal’ is a slice of quartz, and the most common application for these components is to control the frequency of very stable and accurate oscillators. There is a similar type of component called a ‘ceramic resonator’, which use a piece of ceramic material instead of quartz. These are generally of lesser quality than a quartz equivalent, and a circuit that operates with one type of component will not necessarily work with the other. It is therefore advisable to use the specified type of component and they should not be regarded as fully interchangeable.

The main electrical characteristic of a crystal, and the only one that users are normally concerned with, is its operating frequency. This can be anything from a few tens of kilohertz to many megahertz. Crystals for operation at very high frequencies are not a practical proposition as they would be very fragile, but there are ‘overtone’ crystals for operation at high frequencies. These are designed for use in special oscillator circuits where they operate on a harmonic (multiple) of the fundamental frequency. They are normally used at three, five, or seven times the fundamental frequency.

A range of standard case styles are used for crystals. These have names such as HC6/U, HC25/U, HC33/U and HC49/S. Some of these have pins that are designed to fit into matching holders, but these days most crystals have leadout wires and are simply soldered direct to a printed circuit board. It is important that wire-ended crystals are soldered into place quite quickly so that overheating is avoided. There is otherwise a risk of the component losing accuracy, and in an extreme case one lead could become detached from the crystal internally. Crystals vary significantly in physical size (Fig.4), so it is important to obtain components that have a suitable case style as well as the correct operating frequency.

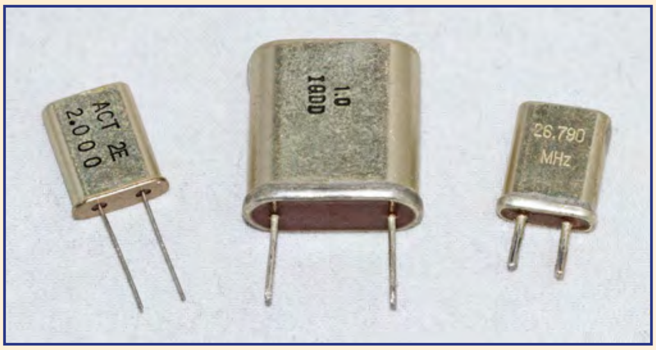


Fig.4. It is quartz crystals that make the digital world ‘tick’. The two on the left are 2 and 1MHz clock crystals, while the one on the right is a fifth overtone high frequency crystal

Choked up

An inductor is a very simple type of component, basically just a coil of wire on a former of some kind. Real-world inductors usually have the wire wound on a ferrite core, or a core made from some other substance that reduces the amount of wire needed to produce a given amount of inductance. Low frequency inductors are sometimes based on ferrite toroids (rings), which further increase efficiency. For even higher efficiency, a pot core can be used, as in the three examples of Fig.5. This is really much more than a core, since it also surrounds the coil of wire.

Low-current inductors for use at radio frequencies are known as ‘chokes’ or ‘RF chokes’. Modern chokes mostly have axial leads and look similar to resistors. It is important to realise that these are strictly for use at high frequencies and with small currents. Trying to use them in something like a switch-mode power supply circuit will result in the circuit failing to work. It could also result in the inductor burning out, and there could be damage to other components in the circuit. For low-frequency applications it is important to obtain an inductor that is specifically

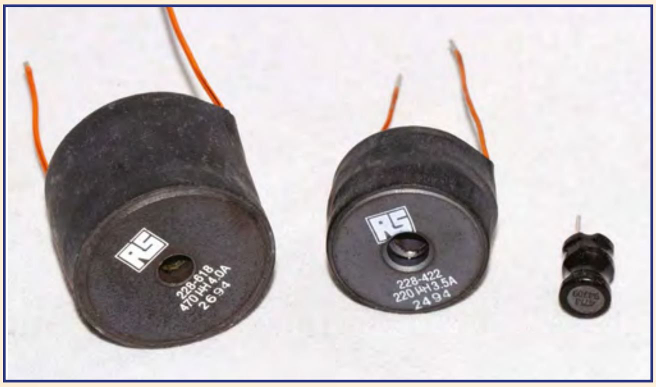


Fig.5. Low-frequency inductors such as these are often wound on pot cores, which are actually rather more than just cores. The two large inductors here are designed to handle high currents

designed for low-frequency circuits, has the right value, and an adequate current rating.

Relays

A relay is based on a normal mechanical switch, but the switch is operated via an electromagnet rather than manually. This is a rather low-tech way of doing things, but relays have definite advantages over semiconductor switching devices such as thyristors and triacs. There is no significant power loss through the mechanical switch contacts, and therefore no heatsink is required when controlling high current loads. With no electrical connection between the controlling circuit and the load, there is complete electrical isolation between the two. Relays are old technology, but they are still very much in use today.

There are relays that just give simple on/off switching, which is all that many applications require, but this does not seem to be the norm. Most of these components have more complex contact arrangements such as two, four, or even six sets of changeover contacts. These contacts are often underutilised in real-world applications, leaving many tags unused.

Unless you know what you are doing it is probably best to use the specified relay and avoid using substitutes. Apart from the usual physical considerations that can make it difficult to use an alternative component, the solenoid must have the correct voltage and resistance ratings, the contacts must have suitable voltage and current ratings, and the correct method of connection has to be sorted out.

READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

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All letters quoted here have previously been replied to directly

Email: editorial@wimborne.co.uk

★ LETTER OF THE MONTH ★

Australian kits and components

Dear editor

I received a subscription to *EPE* as a Christmas present this year and have enjoyed most of the articles presented in it. However, there is a problem associated with some of the constructional projects. Most seem to be reprints from *Silicon Chip* magazine, which I believe is produced in Australia; possibly why the components and kits seem easier to source there.

I have tried to get the components in the UK, but this has not been easy as you need to go to a number of suppliers to get all of the items and in some cases there are many options for the same IC, which perhaps needs a more detailed specification in the list of components. An example is the LMC6482 dual op amp. The Element14 site gives many variations/options for this chip.

I am aware that you cannot recommend suppliers and you state 'We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers'; however, do you check they are actually available from your advertisers?

I am fairly new to building your projects, but feel that the component supply problems mean that it is unlikely I will be able to complete any of them without spending a considerable amount of time contacting the suppliers.

Perhaps you might consider encouraging UK-based suppliers to produce 'complete kits' for your projects. It would make life so much simpler for your readers.

Glenn Jones, via email

Matt Pulzer replies:

Glenn, congratulations on your Christmas present and welcome to EPE*!*

Yes, we have an arrangement with Silicon Chip *magazine whereby we use the best of their projects.*

Yes, we do check that kits are available, but as with all things, supply levels can fluctuate. In fact, we go to some trouble to make sure that components are available – either as kits or standalone components. Generally speaking, it is best to buy a kit whenever possible and with the globalisation of the economy, p&p from Australia usually adds surprisingly little to the overall cost of a project and delivery is within a week – see: ***www.jaycar.co.uk***

If you have a particular problem in locating or choosing a component then I strongly advise you to visit our Chat Zone *forum:* ***www.chatzones.co.uk*** *– it is a friendly place, with people always ready to help and answer questions, however basic or simple, so don't be shy!*

I do understand that buying components individually can seem daunting at first. Usually, the cheaper version is the right one for our projects. If you need a more exotic version then we will usually spell that out in the text. For semiconductors, do make sure you get the correct casing for a device. Keep an eye on our regular column Practically Speaking*, which often addresses component selection.*

Ignition project question

Dear editor

I have a quick question about the *High-Energy Electronic Ignition Project* (Feb 2014 issue of *EPE*, page 10). I note that there is a connection to a 12V 'points' system in an automobile, as shown in Fig.4 (a). When the points open there will be 12V (through 100Ω) applied to the 5V-powered PIC microprocessor. Surely this is curtains for the PIC?!

Sam Gailbreath, by email

John Clarke (project designer) replies:

Good question! The key to this is the third para after the 'Circuit description' heading on p.13. The pin 6 input is protected from voltage spikes by a 2.2kΩ resistor. This limits the current if the internal clamping diodes between the input and each supply rail conduct. The associated 1nF capacitor provides high-frequency filtering to prevent false triggering.

In more detail – current flows through the 100Ω and 2.2kΩ resistors. This is around 3mA and the internal diode at RB0 clamps the voltage to just over 5V. The microprocessor is not damaged. We did not use a voltage divider to reduce the voltage so that the triggering remained reliable for low battery operation, such as during engine cranking.

Guitar valve amp

Dear editor

I like the sound of valve guitar amplifiers. I used to have a 1970s Selmer Treble & Bass 50, which got stolen, and I miss it terribly. Sadly, to replace it on eBay costs about £500.

So, I am hoping to build myself a amp, from 12W upwards, perhaps even in the 25-50W range using EL84s and/or EL34s. (However, I might well use a modern supply, avoiding one with rectifier diode valves).

Modern, commercial amplifiers are so very expensive. I have two questions: 1) Do you have some circuits in 'back issues' for such amplifiers that can be ordered? 2) Do you have plans in the pipeline in a future issue for such a project.

I'm sure there are many guitarist/musicians with an electronic background (but perhaps with no design experience) like me, looking for such a project.

Many electric guitar players are returning to valve amplification – the sound with transistor or even hybrid amps is just not the same.

I am retired, but have qualifications in electronics, and worked in the 1970s with lots of valve circuits. (It's worth remembering that valve circuits can 'bite' – I got a poke off an anode from a CRT on a French TV that wasn't grounded. It threw me back several feet,

and I've always been very respectful of valves and their voltages since then.)

I'm sure that if you offered a 50W valve amplifier, but with 25W or 120W variants, then it would be very popular – especially if you could get a third party to source all the components into a kit.

David White, by email

Matt Pulzer replies

A good idea, although at the moment we do not have any plans for a valve amp. I will certainly give it some consideration and ask one of our regular audio contributors if he might be interested.

In the meantime, you might want to ask around at our forum: ***www.chatzones.co.uk****. I'm sure you will find fellow valve enthusiasts there who may well be able help you.*

Last, but not least, let me reiterate David's caution. Valve circuits operate at high voltages and can definitely be dangerous.

Sonovox

Dear editor
Just a quick note about an idea for *EPE*; how about coming up with a circuit for the 'Sonovox' device? (The inventor was Gilbert Wright.)

Basically, you held two transducers up to your throat, and an amplifier would feed any sound source into the transducers – out of your vocal chords would come sounds like a train or any musical instrument, an amazing device.

There are quite a few videos on YouTube about it, but very little information on how to build one.

My research into the transducers used in Sonovox show that it is essentially a mid-range tweeter, similar to those in hi-fi speakers. A company in the states does a range of these: **www.parts-express.com**

Alan Roantree, by email

Matt Pulzer replies:

It's certainly an interesting idea, although I must confess I have no idea how to make one. Do any readers know Sonovox design details?

Sourcing the L165V

Dear editor
Love your magazine – technical, reliable and above all with no 'side' to it! As you know, Mike and Richard Tooley are currently producing a series of articles centred around the Raspberry Pi. One of the topics highlighted in the March issue was digital-to-analogue conversion – a very important matter in Pi circles. The article provided an 'additional amplifier stage for use with the DAC', together with a circuit diagram and other helpful details for the builder (pages 43-4). Unfortunately, despite offering 1,076 operational amplifiers, RS Components no longer sell the circuit's pivotal component, the L165V. Farnell assert that the STMicroelectronics L165V Pentawatt-5 is 'no longer manufactured'.

I very much hope that Mike and Richard can include a solution.

John Burton, by email

Mike Tooley replies:

*Thank you very much for the praise, and we're sorry you have had trouble with this device. The L165 in our prototype DAC power amplifier was purchased last year from Rapid Electronics using order code 82-0088. It is also advertised on eBay by several electronic component suppliers (eg, EMS-Electronics Store) but it is worth checking the price as it tends to vary widely. Alternatively BG Microelectronics (****www.bgmicro.com****) carry stocks of this part at a very reasonable price. Alternative power amplifiers such as the TDA2030 could probably be used, but we have not tried this.*

Mini ignition choice

Dear editor
Is the *High-Energy Electronic Ignition System* (Feb/Mar 2014) a replacement for the similar unit featured in *EPE*, Sept/Oct/Nov 2009 (Jaycar KC-5442)? The older project was a programmable unit that could be mapped/varied for an advance curve that could be matched to a specific vehicle or state of tune. The new unit uses cheaper IGBT technology, but does it have the original flexibility?

I own an old Mini-based kit car (quite heavily modified – the ignition curve will be different to a standard Mini or the more highly tuned Cooper S). I want to drive it to the Classic Le Mans this year. However, I don't look forward to the worry of it not starting – I remember the 'will she won't she' days only too well, and I want a more modern/reliable ignition system.

I think the 2009 unit seems to be the best one for me, but would like your opinion.

Tony Gerrard, by email

Matt Pulzer replies:

I am not an auto expert, but from rescanning the earlier project I would say your summary is correct.

The 2009 project offers much greater flexibility at the expense of using 'inferior' Darlington transistors. The recent project is really more about upgrading a mechanical system to an electronic one.

My advice – subject to the qualification above – is that if you simply want a cheap and simple route to electronic ignition, then go for the 2014 project. If you enjoy tinkering and experimenting with cars, and you are reasonably experienced in this area, then you would enjoy the 2009 project.

It's always fun to hear where an EPE *project ends up – Classic Le Mans sounds fantastic. Best of British luck to you and your Mini's spark plugs!*

Old projects

Dear editor
I am enquiring about the *EPE* July 2000 project *PIC-GEN Frequency Generator/Counter* circuit and the May 2001 *PIC Graphics LCD Scope* circuit. Can I order the programmed PIC chip from you?

Steve HG8GL

Matt Pulzer replies:

Thank you for your question about two PIC projects. I am very sorry but we no longer support such an old project, and sadly the author has now passed away. You may have luck if you ask on our forum, for example: ***www.chatzones.co.uk/discus/messages/5557/7094.html***

Teach-In code

Dear editor
I find it hard to read the way you print *Teach-In 2014* source code! If this code is available online, I'd like to know where... it's a time waster typing it in.

Ted Mieske, via email

Matt Pulzer replies:

Hi Ted, I'm sorry you've found the admittedly long pieces of code a 'time waster' to type in, but to be honest I agree! So, you can now find all the Teach-In 2014 *code in the* Library *section of:* ***www.epemag.com***

Swatting bugs

Dear editor
I think I've spotted a couple of 'bugs' in March's *Teach-In 2014*. The equations at the bottom of the rightmost paragraph on page 40 are inconsistent.

Also, the program at the top of page 43 has a bug that forces the output to remain at zero.

Godfrey Manning G4GLM, Edgware

Mike Tooley replies:

Thank you Godfrey, you are quite right, the correct versions are as follows:

This yields the following relationship:

V_{out} = Digital code × (3.3/4096)

From which:

Digital code = V_{out} × (4096/3.3)

Hence, if we need an analogue output of exactly 1.5V the required digital code would be:

Digital code = 1.5 × (4096/3.3) = 1861

For the software, a small correction eight lines from the top of page 43:

```
voltage = step * 0.3
```

Not

```
voltage = step * voltage
```

PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Development board programming

WE move away from assembly language programming now and into the high-level language, 'C'. Since its creation 40 years ago, the 'C' programming language has become a hugely popular language used in a diverse range of applications, and many of them are ubiquitous – microwave ovens, washing machines, mobile telephones, aircraft control systems, Internet routers to name a few. While languages such as Python, PHP, Java and Ruby may be more familiar, 'C' is the language of control. It's what makes our digital society function.

High Level

Let's follow that rather grand introduction with a more humble overview of the language. First, when we refer to 'C' as a high-level language, what do we actually mean? 'High-level' refers to the way the language allows us to express our programs in a more abstract way, abstract from the underlying microcontroller hardware. We write statements that express our *intent* rather than directing the microcontroller to perform specific machine-level tasks. For example, consider the situation where you would like to perform the following task:

Store the value 56 (the current voltage) in a variable for later use

In assembler, we might say the following to achieve that:

```
; load the working register with the value 56
movlw .56

; store the contents of the working register
; in RAM location 20.
movwf 20
```

That's rather messy; our original task didn't make reference to either a 'working register' nor did it talk about specific RAM locations.

In 'C', the equivalent program statement would be:

```
voltage = 56;
```

That's a lot clearer, more concise, and *more accurately reflects what we wanted to achieve*. Even without comments, it is easier to understand.

That example was working with a variable that could take a value between 0 and 255 – a byte variable. Things get even better when we work with variables that are larger than a single byte. Here is the same problem expressed using a four-byte variable (a long integer:)

```
; load the working register with the value 56
movlw. 56

; store the contents of the working register
; in RAM location 20.
movwf 20

; clear the upper three bytes of the variable
clrf 21
clrf 22
clrf 23
```

But look at what happens to the 'C' program statement:

```
voltage = 56;
```

It's the same!

The only difference is how you declared the variable called 'voltage'. In the first example, it would be declared as:

```
unsigned char voltage;
```

In the second, as:

```
unsigned long voltage;
```

If you were to write those 'C' statements in a program, it is very likely that the compiler would create the same assembly language code as shown above. In real applications the compiler can (and does) examine the rest of your source code and make some *very* smart deductions about what is going on, enabling it to simplify and 'fold' several related statements together, making common 'short cut' assembly language sequences and even find 'dead code' that it knows can never be executed, and remove it completely. It's rare that one would need to resort to assembly language programming, and even then, only for very short pieces of code.

Not so high level

In some respects, 'C' is not really a higher level language at all – in much of its use, it is nothing more than a powerful assembler language. It's certainly a view we take, and believe this is where most of the language's power and efficiency derive from. It's often said that the best 'C' programmers are those who came to the language from assembly.

In this series of articles we are not going to teach the programming language itself; there are plenty of excellent tutorials for that on the Internet, and books in the library. A twenty-year-old book on 'C' is still going to be a useful introduction; the core of the language has not changed much in that time (certainly from our perspective with small microcontrollers.)

What we will be addressing is what we see as the 'missing link' in many of these tutorials and books – how to construct a microcontroller program, how to *understand* what gets created, and how to debug that application when it goes wrong.

Creating the new template

We will walk through the creation of the template project files, mimicing what we did for the assembly language template. You don't need to follow directly – the complete project files can be found on the magazine website against this month's article if you would rather download them than type them in (although you will find it a useful exercise if you are unfamiliar with MPLAB-X.)

Start MPLAB-X, and then click **File -> New Project**. Click **Next**, then from the two drop-down lists select 'Advanced 8-bit MCUs (PIC18)' and 'PIC18F27J13'.

Click **Next**, and then click on the Hardware Tool (programmer) you intend to use. We are using the PicKit3. If you will not be using a programmer, select the 'Simulator' tool.

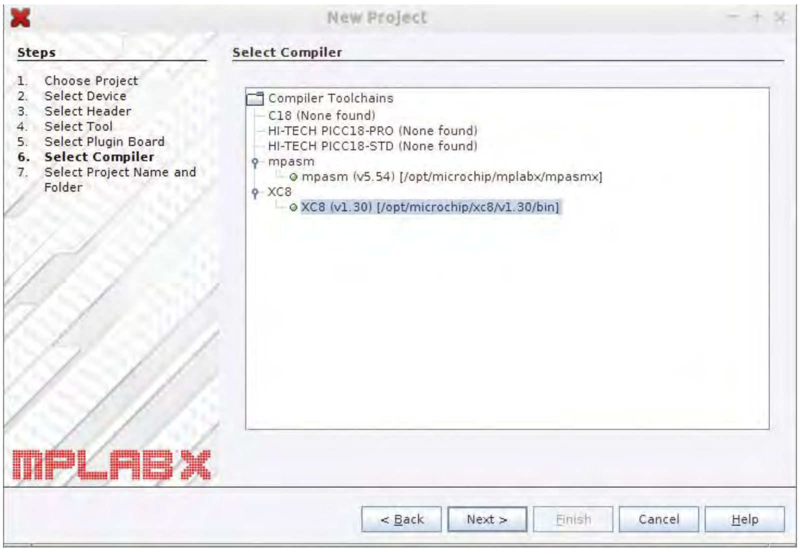

Fig.1. Compiler selection dialog

Click **Next.** You are now presented with a choice of compiler, hopefully similar to Fig.1. If not, go back and install the XC8 compiler as mentioned last month. If all is good, highlight XC8, and click **Next**. In theory, you could have several different compilers installed, and for professional development this is quite likely, but for us hobbyists there is no need for more than one.

We are now prompted to enter the project name. This will map directly to the name of the directory in which the project files will be stored. Let's call ours 'PIC18F27J13-C-Template'. Notice how the full path to the files is shown below, in the 'Project Folder' field. All other options can be left at default, so click **Finish.**

At this point you will be presented with the main MPLAB-X screen, from where you will enter your code and debug your projects. The content is very similar to MPLAB – they do, after all, do the same thing – but MPLAB-X is a more modern and powerful tool, with extra 'bells and whistles', as we shall see.

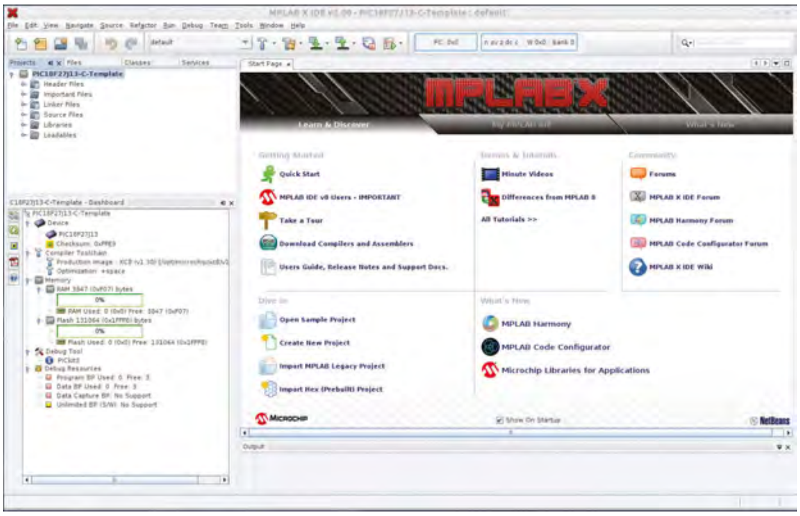

Fig.2. Main IDE screen

Fig.2. shows the main screen layout. It's divided into five key areas; the menu along the top (with matching short-cut icons,) the 'Projects' window to the top left, which enables you to navigate through the files in your project, the 'Dashboard' below that, which shows useful information such as how much RAM and FLASH has been used. At the bottom is the 'Output' window that displays warning and error messages from the various tools as they run – compilation errors from the compiler, connection issues from the debugger, etc.

The remaining area, showing the 'Start Page', is where your files will be displayed. The Start Page is a little different as is contains links to videos, webpages and options within the tool. We normally close this by clicking on the 'x' next to the name on the tab. You can get it back again by selecting the option **Window->Reset Windows** from the main menu.

Back in the 'Projects' window, you can see our project name and underneath it the categories of file types. Just as assembly language programmes have source files and include files, so 'C' programs have source files and header files. There are other file types that are important – makefiles and library files – but we do not need to concern ourselves with these yet; modifying or understanding those is an advanced topic that we can pick up on later. We can build some very complex projects without needing to be aware of those files.

Right now though, we have an empty project. This is a great time to find out what 'project files' get created, as we have not added our own yet. Did you remember the full directory path to the project files when we started MPLAB-X? If not, place the cursor over the project name in the 'Projects' window, and it will pop up.

Navigating to the project location on your disk using windows explorer, the first thing to notice is that the files live in a directory called projectname.X. This directory and everything underneath it constitutes your project. You should note that MPLAB-X recognises a directory with the .X suffix as the root of a project, so don't go renaming it.

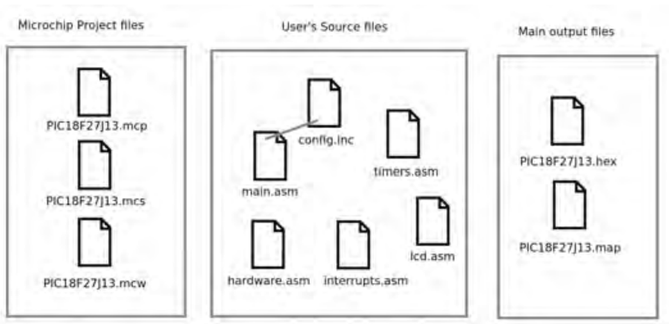

Fig.3. Assembly language file layout

The 'empty' project contains thirteen files, none of them of any interest to us, as they are used by the IDE itself. You can ignore them and should never edit them, but when you back-up your project make sure all these files are backed up too. MPLAB-X will not start correctly if they are missing or corrupt.

Files fall into one of three categories: Microchip project files (files that you never edit directly, as mentioned above) your source files (that we edit to add the functionality of the program) and the output files, created when we 'build' the project. Just as with assembly projects, the main output files are the .hex and .map files, and these files are in the same format whether you build an assembly language project or a 'C' project. No particular surprise, because the XC8 compiler converts the 'C' files into assembly, and from that point it's just like converting an assembly project. Fig.3 and Fig.4 show the difference in file layouts between the two project templates.

Where assembly programs are placed in .asm source files, assembled (which translated the textual representation of the instructions into machine language byte codes) then linked together, C source code is placed in .c source files, compiled (directly to machine language) and then linked in exactly the same way as assembly. In fact, you can have a project that consists of both assembly and C source files that get linked together if you wish, although this is not terribly common – there is very little that can be done only in assembly language.

So let's go ahead and created our template files, creating a file set as shown in Fig.4.

Creating our template

In the 'Projects' window of MPLAB-X, right click on the line 'Source Files' and select **New->C Main File...** This will

be our top level application source file where our main() function will live. So let's call it main.c.

Type **main** in the 'File Name' field, and click **Finish**.

The filename will appear underneath the 'Source Files' entry. Double click on main.c, and the file will appear in the main window on the right. It has template contents already, to get you started.

We will finish creating the remaining files now though, before we dive in and start adding code. Right click again on the line 'Source Files', but this time select **New->C Source File...** Enter the name as **timers** (no need for the extension – this is automatically created) and click **Finish**. This time, the file contents will be empty – MPLAB only provides a template for the main file. No problem, we will be creating our own template content anyway!

Now we can create the header file to match timers.c. Right click on the line 'Header Files' and select **New->C Header File...**

Enter the name **timer** and click **Finish**.

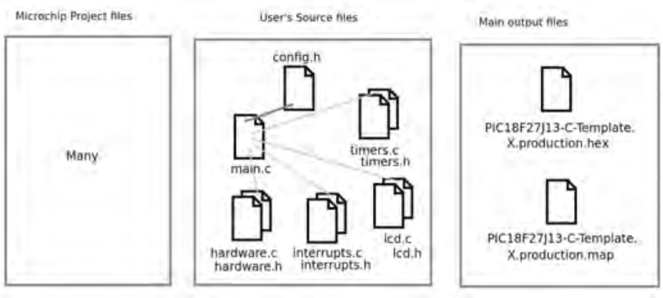

Fig.4. 'C' language file layout

Header file content

You will notice that the header file contains a short comment field and some strange lines of text. This text forms the standard header and footer found in all header files:

```
#ifndef TIMER_H
#define      TIMER_H

the rest of the header file goes here..

#endif       /* TIMER_H */
```

The purpose of this is simple: if this header file is accidentally included more than once (which is quite possible, as it could be included in another file by a source file) then it stops the content of the header file being included more than once. It's a simple programming trick that costs nothing and stops all manner of bugs appearing. *Always use it!*

Then there is this section:

```
#ifdef      __cplusplus
extern "C" {
#endif

the rest of the header file goes here..

#ifdef      __cplusplus
}
#endif
```

This is a bit of special 'magic' code that enables our source files to be re-used in programs written in the C++ language (a language that is very similar to C.) Again, ignore this text and just include it in your header files.

So we have created the main.c source file, and the source and include file for the timers module. Go ahead and do the same for the remaining files, lcd.c, lcd.h, interrupts.c, interrupts.h, hardware.c, hardware.h and config.h. Or alternatively, just download the files from the *EPE* website (**www.epemag.com**) against this month's issue. You should end up with a project layout similar to Fig.5.

Creating the content

We finish off this month by starting to fill in the content, 'porting' the code from the original assembly language template. We start with the configuration bits, which we will place in their own file, config.h.

```
#pragma config WDTEN = OFF
#pragma config XINST = OFF
#pragma config IESO = OFF
#pragma config FCMEN = OFF
#pragma config DSWDTEN = OFF
#pragma config OSC = INTOSCPLL
#pragma config CFGPLLEN = ON
#pragma config PLLDIV = 2
#pragma config PLLSEL = PLL96
#pragma config CP0 = OFF
#pragma config WDTPS = 1
```

Note how this is similar to the assembly format, but not exactly the same.

To actually *use* this config file, we have to 'include' it in our main.c source file. Just add a reference to it immediately below the existing two include references:

```
#include <stdio.h>
#include <stdlib.h>
#include "config.h"
```

Notice that we used double quote rather than <>. This is an instruction to the compiler to look in the project directory rather than the compiler directory for the file.

This code should build (select **Run->Build Project**) although it wont do anything interesting – yet!

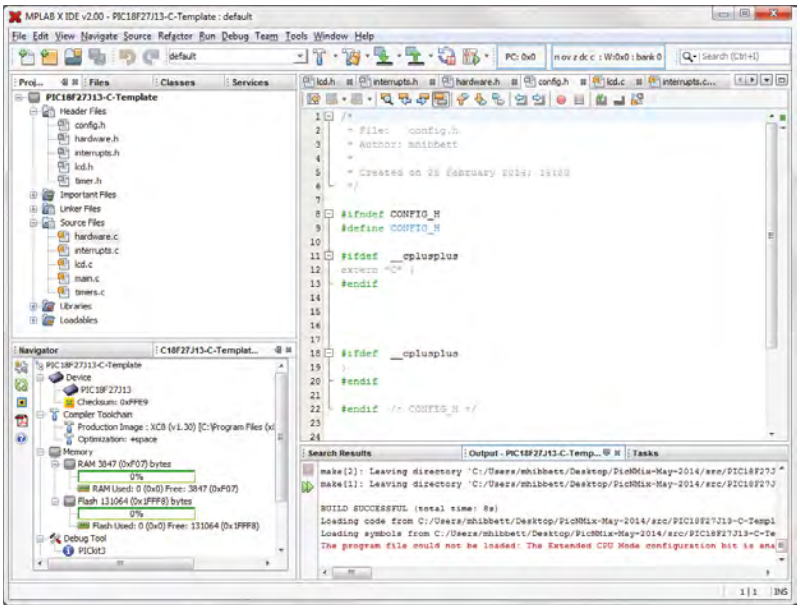

Fig.5. Completed template file set

Next month

We will complete the port of the template code from assembly language next month, and finally see our kitchen timer implemented in 'C'. We'll also take a look at interfacing to a 1.8" colour graphics LCD panel, available for less than £4!

Kickstarter update

As we write this article, our Kickstarter campaign (to manufacture a large number of our development boards for sale at low cost, if you missed last month's issue) is still in development and not yet approved by Kickstarter themselves – they have their own quality and submission standards that we have to pass. We hope, however, that by the time you read this it will be launched, and available to view on kickstarter.com. Look for 'Low Power, Low Cost Development Board' on that website to see if we were successful.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at @MikeHibbett, and from his blog at mjhdesigns.com

Max's Cool Beans

By Max The Magnificent

As I mentioned in a previous column, several years ago I saw a really funny image of a 'Man *vs* Woman' piece of pseudo-electronic equipment (**http://bit.ly/1hvRvHv**). The idea is that the 'Man' part has a single switch and an associated light; the switch is in its active position and the light is on. I take this to mean that we men are inherently uncomplicated (simple) creatures. By comparison, the 'Woman' portion of the device is festooned with the most baffling array of knobs and dials adorned with meaningless annotations.

Like most men of my acquaintance, I often find it difficult to wrap my brain around my wife's moods and to understand where she's coming from. Thus it was that I decided to construct my 'Pedagogical and Phantasmagorical Inamorata Prognostication Engine' (where Inamorata comes from the Italian innamorata, meaning 'a woman with whom one is in love').

The thing is that, when you come to look at the original 'Man *vs* Woman' unit, it's really not all that well done. It's basically a collection of bits and pieces that the creator rooted out of his (or her) treasure chest and stuck onto a simple aluminium panel. I wanted to do something a little tastier for my Inamorata Prognostication Engine, so I decided to house it in a 1929 wooden radio cabinet (**http://bit.ly/Ngls1O**) and give it a Steampunk look and feel.

This cabinet is absolutely beautiful. There's a large rectangular opening at the top, and an interestingly shaped opening at the bottom. These are going to be filled by two brass panels. In turn, the brass panels will be populated with antique knobs and dials and switches and analogue meters in Bakelite cases. I've been collecting all of this stuff for years.

There is going to be a really nice large meter in the upper right-hand corner of the top panel. This will display the full gamut of female emotions, from 'Extremely Disgruntled' to 'Fully Gruntled.' The idea is to manipulate the other controls so as to get this meter in its 'Green' or 'Happy' zone. And one may be able to get tantalizingly close, but…

Wrongdoing!

The bottom panel will boast two smaller meters, a modestly-sized red push button (do not press the red button), and three black push buttons. The black buttons equate to things like 'flowers' and 'chocolates' and 'hugs.' Pressing these occasionally works in one's favour, but using them too enthusiastically will trigger the 'suspicion of wrongdoing' algorithm. One of the meters in the lower panel will reflect the current phase of the moon. Suffice it to say that the time of the full moon is not typically regarded as a happy one. Meanwhile, the other meter will reflect the time until the next blue moon, which is the third of four full moons in a season. A blue moon occurs only once every two or three years, and its occurrence may herald a happier period (or not, as the case might be).

There are also going to be five rotary potentiometers that are used to enter the characteristics of one's Inamorata. For example, one will be used to specify overall 'mood,' ranging from 'Sweet and Happy' to 'Homicidal Maniac.' (Perhaps this would be an appropriate time to mention that any annotations on the panels will be in Elvish Feanorian Script, which means one's Inamorata won't be able to read them.) The really cunning thing is that these potentiometers are motorised, so once you've rotated them to the desired settings and locked these values in, if anyone (like one's Inamorata, to take a random example) should decide to modify any of the values, the other dials will automatically adjust themselves to provide appropriate compensation (after some period of time, all of the knobs will surreptitiously return to their original positions).

As you might imagine, I'm having a lot of fun building this and creating the control program for my Arduino Mega. Of course, there are always 'gotchas' along the way, and these are sometimes exacerbated by the fact that I am not a professional programmer. Recently, for example, I was working on an algorithm to calculate the number of days until the next full moon, and I ran into a little problem.

Julian day numbers

There's something called Julian day numbers, in which each day has its own number. If you know the Julian numbers of two days, you can calculate the number of days between them by simply subtracting one from the other. Purely for the sake of this discussion, let's assume that the period p of the moon's orbit is exactly 28 days. Let's also assume that my program knows the Julian day number of some reference full moon in the past and it knows today's Julian day number. Again, for the sake of discussion, let's assume that the difference d between today's Julian day number and the number of our reference full moon is 175 days.

The formula I'm using is (p – (((d/p) – floor(d/p)) * p). This really isn't as difficult as it looks. Let's start with (d/p) = 175/28 = 6.25, which means there have been six and a quarter full moons since our reference full moon. The floor(d/p) performs the same division, but throws away the remainder, leaving us with 6.0. Thus, ((d/p) – floor(d/p)) leaves us with the remainder of 0.25. Multiplying this by p gives us 0.25 × 28 = 7 days since the last full moon. And subtracting this from p gives us 28 – 7 = 21 days until the next full moon. Easy-peasy, eh?

Of course, we all know that the period of the moon's orbit is not exactly 28 days. I performed a Google Search 'How long does it take the moon to orbit the earth?' and received the following response: 'The sidereal month is the time it takes to make one complete orbit of the earth with respect to the fixed stars – it is 27.321661 days.' So I plugged this value into my algorithm and… consistently failed miserably in determining how many days it was until the next full moon.

At first I thought I was messing up my casting operations when converting variables of type 'long' into 'floats' and/or variables of type 'float' into 'ints' – but when I worked

things out by hand using pencil and paper I obtained the same (inaccurate) results. I was pulling what little hair I have left out of my head by the time I finally tracked the problem down. The thing is that the Earth is moving around the sun, so as opposed to using the sidereal month with a value of 27.321661 days, I should have been using the synodic month value of 29.530588 days. As soon as I plugged this value in, my algorithm started working perfectly (phew!).

I have so many other things to tell you, such as the fact that my panels are being cut out of 0.1inch thick brass sheets using a computer controlled water jet cutter as I pen these words, but this will have to wait until a future column. Until next time, have a good one!

Inamorata cabinet with mock-up of the panels resting on top

LED constant-current drives

THE following question was posted by ***atferrari*** on the *EPE Chat Zone* forum:

Switchable constant-current source for a green LED (Fig.1). Switching is commanded with logic signals +5V and 0V and constant current is around 15mA to 20mA. Before I buy components, given the circuit below, will it work if Vcc is just 5V, replacing the MOSFET with a 2N7000?

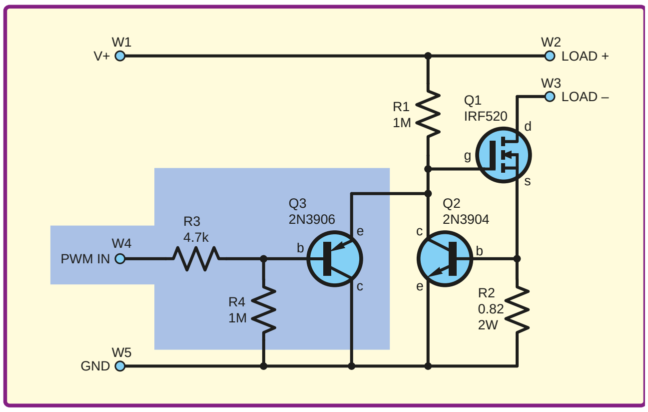

*Fig.1. Circuit posted by **atferrari***

We will discuss the operation of the current source in this circuit later, showing how it is able to provide a near constant LED brightness, even if the supply voltage varies. First, we will look at the specific question about the 2N7000 and then look at why in general we might need to use constant current source as an LED driver.

We expect that ***atferrari's*** main concern about the 2N7000 (Q_1 in the circuit in Fig.1) was whether or not it could be switched on using a 5V supply. Fig.2 shows the forward transfer (transconductance) characteristics from the data sheet, from which we can see that a gate-source voltage, V_{GS}, below 3.5V should always be sufficient to obtain a collector current of 20mA or less. This is reinforced by the datasheet stating that the maximum threshold voltage for the 2N7000 is 3V.

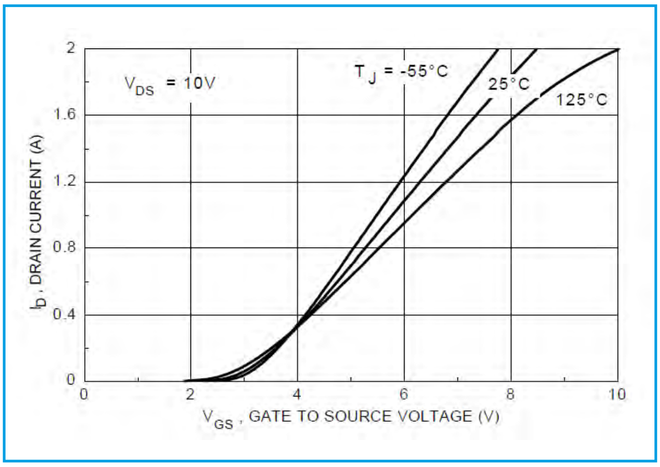

Fig.2. Plot of the 2N7000's transconductance characteristics from the datasheet (www.fairchildsemi.com)

The 2N7000 is designed for switching much higher currents than 20mA, where it may require a larger V_{GS}, but at low currents, the 5V supply will be sufficient. The voltage at the gate of Q_1 is Q_1's V_{GS} plus the V_{BE} of Q_2, which will definitely be less than 0.8V, so the voltage at Q_1's gate is unlikely to be at above 4.3V for currents in the stated range. Therefore, the 2N7000 should operate in this circuit on a 5V supply.

The 2N7000 maximum ratings are not exceeded. The maximum V_{DS} is 60V, the maximum continuous V_{GS} is 20V, and the maximum continuous drain current is 200mA. These are well above the 5V, 20mA level quoted by ***atferrari***. If the V_{DS} of Q_1 was the full 5V supply voltage, at 20mA drain current it would dissipate 100mW. The voltage will be less than this due to the voltages across the load and R_2, but even this over-estimate of power is well below the 2N7000 maximum of 400mW.

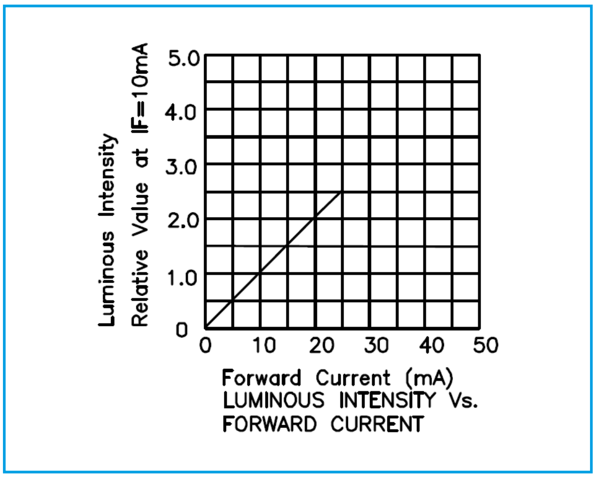

Fig.3. Relationship of forward current and luminous intensity for an example green LED (Kingbright L-493GT, from the Kingbright datasheet)

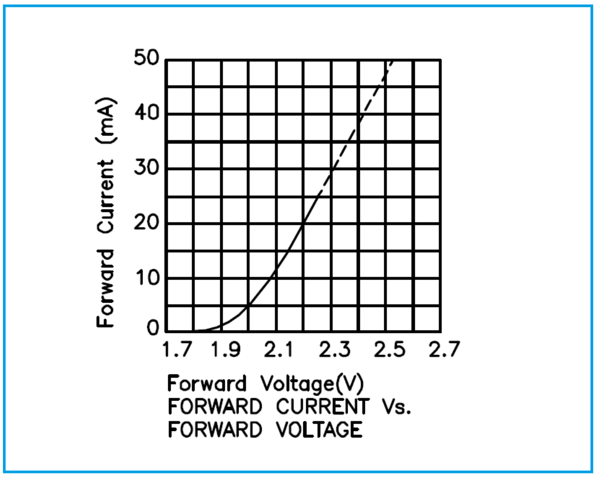

Fig.4. Relationship of forward voltage and current for an example green LED (Kingbright L-493GT, from the Kingbright datasheet)

Current controlled

The reason ***atferrari*** is asking about a constant-current source circuit is because LEDs are current-controlled devices – in that the light output (brightness) is just about directly proportional to the forward current (a linear relationship) – so LEDs are often driven using constant currents. This is illustrated in Fig.3, which shows the relationship between forward current and luminous intensity for a typical green 5mm LED (specifically the Kingbright L-493GT). So it is the current, not the voltage which sets the brightness.

Fig.4 shows the relationship between forward current and voltage for the L-493GT, which follows the typical exponential diode curve. By implication, from Fig.3 and Fig.4 together, the brightness does not vary linearly with forward voltage. The LED's characteristics shown here may be similar to those used by ***atferrari*** (10mA to 20mA is within the operating current range, 25mA is the maximum forward current), although he does not give very specific details in his post.

Two individual LEDs of the same type will have very similar brightness at the same forward current (I_F), but may have different forward voltage drops (V_F) at this current. Possible characteristics of two individual LEDs of the same type are shown in Fig.5. With the same forward voltage, the LEDs may have different forward current and hence different brightness. Thus driving the LED with a circuit which does not set the current to a specific value may lead to variations in brightness for individual LEDs of the same type.

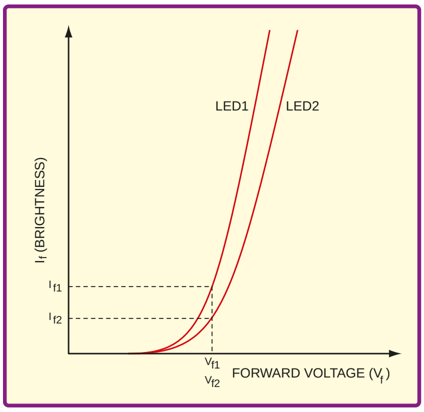

Fig.5. With the same forward voltage the LEDs may have different forward currents and hence different brightnesses

This is a key fact that needs to be considered when designing LED drive circuits, given that it is very common when using multiple LEDs to want to have all the LEDs at the same brightness for aesthetic reasons. In ***atferrari's*** post there was no indication that driving multiple LEDs was required, in which case a simple transistor switch may be sufficient. This fact was discussed in the *Chat Zone* thread.

Another reason that a constant-current source may be required is if the power supply voltage is variable, for example over the life or charge cycle of a battery. A constant-current source would maintain the same current through the LED and hence maintain a constant brightness as the supplied voltage varied. This current would be maintained if the supply remained within the operating voltage limits of the current-source circuit. With a varying supply voltage, a constant-current driver may be needed even for a single LED, but again ***atferrari*** does not give detailed information about the power supply.

As an example, for a single LED and series resistor, assume we have a supply that can vary from 6V to 3.6V as the batteries discharge (for example, this might apply to, say, four standard alkaline cells). If we assume an LED voltage of 2.2V at 20mA then a series resistor of 190Ω would be needed for a 6V supply. When the supply falls to 3.6V, the LED current will be about 8mA, with about a 2.07V forward drop; the remaining 1.5V will be across the resistor. These figures are approximate, but more or less correspond with the graph in Fig.4 and show that the LED current and hence brightness will more than halve over the battery life.

LEDs in parallel

Fig.6 shows two LEDs driven in parallel. This circuit forces the LEDs to have the same forward voltage drop, which means that their forward currents and hence brightness may be different (as in Fig.5). Fig.7 shows two LEDs with separate current-limiting resistors; we can still get problems with variation between individual devices resulting in varying brightness. An example will help explain this.

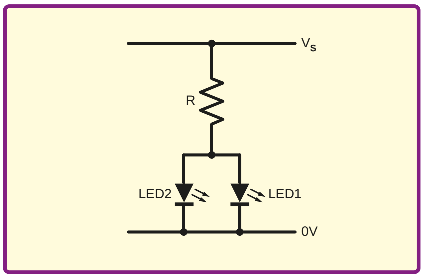

Fig.6. Driving two LEDs in parallel

Assume for the circuit in Fig.7 we have two LEDs with LED1 having a forward voltage drop of 2.2V at a forward current of 20mA. If the supply (V_S) is 5V we have R_1 = 140Ω so that R_1 drops 2.8V and we have 2.2V across LED1. The L-493GT datasheet states the maximum forward voltage at 20mA is 2.5V (2.2V is typical). If LED2 is also connected with R_2 = 140Ω, but has a forward voltage drop of 2.5V due to variations in individual device characteristics, the current in LED2 will be 17.86mA. The difference in current (about 11%) may show up as a noticeable difference in brightness in the two LEDs.

If we use a higher supply voltage, the brightness variation problem is reduced. For example, consider

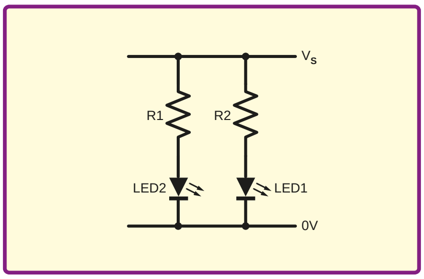

Fig.7. Two LEDs with separate current-limiting resistors

a 24V supply. Let's say we have R_1 =1.09kΩ to get 20mA with a 2.2V drop across LED1, so the LED is of equal brightness to the previous example. Now consider LED2 with a 2.5V drop again and R_2 = 1.09kΩ. The current in LED2 is 19.73mA, almost the same as LED1, so they will be closer to being equally bright (1.4% difference). This comes at a price though – the total power dissipation in the two current-limiting resistors is about 0.87W in the second example, which is almost eight times higher than in the first example. The second circuit is very inefficient.

Fig.8 shows three LEDs driven in series. The current through the LEDs must be equal by virtue of the serial connection, so their brightness will be equal. This approach requires a higher supply voltage – in this case something above 6V is needed. The lowest forward voltage drop available for green LEDs is around 1.8 or 1.9V, which implies that ***atferrari*** could only run two in series from a 5V supply.

Problems

Despite the fact that the circuit in Fig.8 guarantees equal brightness there are still a few potential prob-lems. First, we still have individual variability of the LEDs, so if we build two copies of the circuit then the brightness might not be the same. This may not matter too much if this is for separate projects, but if we need to drive more LEDs than we can have in series across our supply voltage (so we use several LED strings) we are back to a similar problem to that with the circuit in Fig.6. As with the single LED, if the voltage across the resistor is relatively small, which it will be if are trying to maximise the number of LEDs, then the variability will be more obvious.

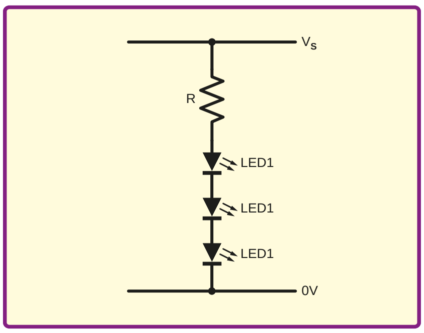

Fig.8. Driving LEDs in series ensures the same forward current but requires a higher drive voltage

Another problem with the circuit in Fig.8 is that the LED current, and hence brightness, will depend on supply voltage. This is exactly the same problem we discussed earlier for a single LED.

Finally, the LEDs in the circuit in Fig.8 may be subject to thermal runaway if conditions cause them to warm up sufficiently. LEDs have a negative temperature coefficient of forward voltage. This means that their voltage drop decreases as temperature increases. In the circuit in Fig.8 this would cause the voltage across the resistor to increase, increasing the LED current. The increased LED current will lead to higher power dissipation, which may further increase their temperature. This temperature increase further increases the current and so on. It is possible for this situation to result in damagingly high currents in the LEDs. This is more likely to be a problem when using a high-power LED, which at 15-20mA is probably not what ***atferrari*** is aiming for.

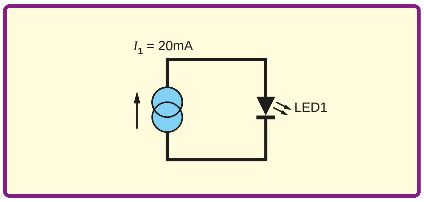

Fig.9. An ideal current source could power an LED directly, but practical current sources are usually just current regulators

Current source

The problem with all the LED circuits described so far is that they are all fundamentally voltage driven, but what we actually want to do is drive a specific current through the LEDs. Thus, we need a current source, rather than the voltage source that we get with a standard power supply or battery. An ideal current source would power an LED directly (see Fig.9), however, practical current sources are typically circuits designed to deliver a fixed current, rather than something like a battery or the mains which act as actual sources of electrical energy. They obtain their power from a conventional voltage-based power supply (see Fig.10) and regulate the current through the load as the load impedance and supply voltage varies.

Current sources connected to ground, through which current flows to ground, are sometimes called

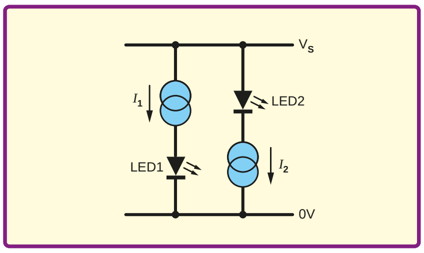

Fig.10. I_1 is a current source or high side current regulator. I_2 is a current sink or low side regulator

current sinks (see Fig.10). The terms 'high side' and 'low side' are also used to describe current regulators, which can be operated connected to the supply and ground respectively.

An ideal current source outputs a particular current irrespective of the voltage(s) required at its terminals to achieve this. This corresponds with an ideal voltage source, which can deliver any current depending on the nature of the load. In practice, of course, voltage sources are limit in terms of current capacity – an AAA 1.5V battery will not deliver 1500A into a 0.01Ω load. Similarly, a real current source delivering 20mA will not deliver the 1kV required to push this current through a 50kΩ load!

Having established the need for a constant-current source for LED driving we can look at how the circuit in Fig.1 works. It uses what is known as a V_{BE} referenced current source, formed by Q_1, Q_2, R_1 and R_2. The other components (shaded in Fig.1) are for switching the current on and off. The most common form of the V_{BE} referenced source uses two bipolar transistors, as shown in Fig.11, but the circuit in Fig.1 with the MOSFET output transistor operates in fundamentally the same way, with Q_2 and R_2 being the most critical components for determining the current.

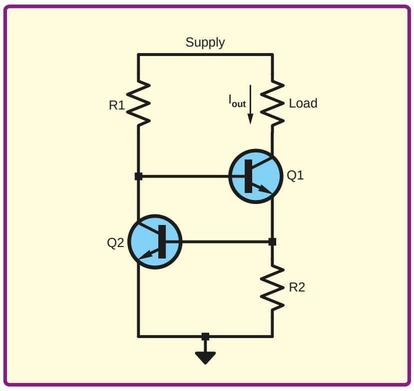

Fig.11. Standard V_{BE} referenced current source using two bipolar transistors

The voltage across R_2 is the V_{BE} of Q_2. Assuming Q_2 is conducting this voltage is going to be fairly constant, probably around 0.6V to 0.7V. This voltage will determine the current in R_2 because Q_2's V_{BE} voltage is across this resistor. So, for example, if V_{BE} = 0.65V and R = 32.5Ω the current in R_2 will be 20mA. If the base current of Q_2 is much smaller than 20mA (which is what we would expect, particularly if Q_2 has reasonably high gain) then the current in Q_1 (drain-source in Fig.1 and collector-emitter current in Fig.11) will be 20mA. Consequently the same current will flow through the load.

It is worth noting at this point that the value of R_2 given in ***atferrari's*** post does not seem appropriate, as it would give a current of around 700mA or 800mA. This was pointed out by forum member **g0hjq** during the *Chat Zone* discussion on ***atferrari's*** circuit.

Equations

The V_{BE} of Q_2 is related to its collector current, which in turn will depend on R_1 and the supply voltage. From transistor physics, the most basic form of the relationship between applied base-emitter voltage and collector current is:

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right).$$

In which V_T is the thermal voltage. V_T is about 26mV at room temperature and is given by kT/e, where T is temperature and e and k are physical constants, the charge on the electron and Boltzmann's constant respectively. I_S is the reverse saturation current, which depends on the individual transistor.

We can rearrange this equation to find the V_{BE} for a given collector current as:

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right).$$

So, assuming I_{out} is equal to the current in R_2, which is V_{BE}/R_2, we get:

$$I_{out} = \frac{V_T}{R_2} \ln\left(\frac{I_C}{I_S}\right).$$

The value of I_C for Q_1 can be taken to be equal to the current in R_1 assuming (with reference to Fig.1) that the MOSFET gate current is zero. The voltage across R_1 is the supply voltage, V_{CC}, minus the voltage at Q_2's gate. This voltage is the V_{BE} of Q_1 (V_{BE1}) plus the V_{GS} of Q_2 (V_{GS2}). So the current in R_1 and hence I_{C1} is:

$$I_{C1} = \frac{V_{CC} - V_{BE1} - V_{GS}}{R_1}.$$

Substituting this into the previous equation we get:

$$I_{out} = \frac{V_T}{R_2} \ln\left(\frac{V_{CC} - V_{BE1} - V_{GS}}{I_S R_1}\right)$$

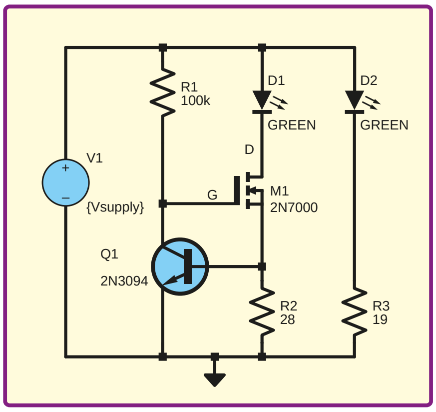

Fig.12. LTSpice simulation schematic for comparing a current in an LED as supply voltage varies when using a current source and series resistor

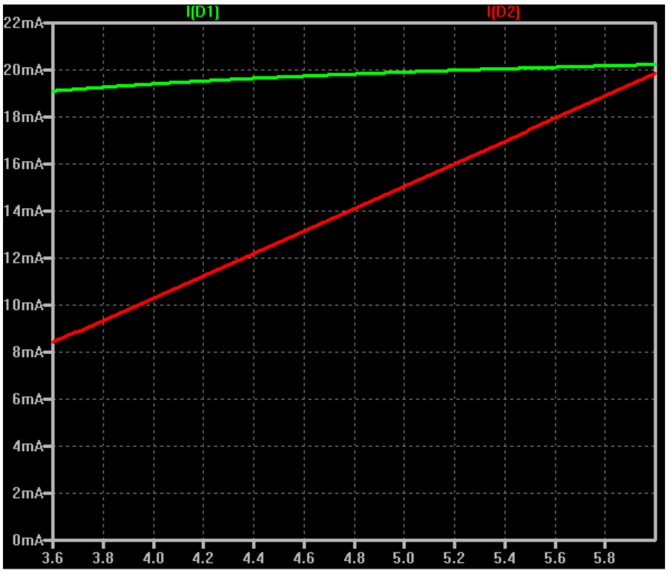

Fig.13. Results from simulating the circuit shown in Fig.12. The current in D1 (green) and D2 (red) is plotted against supply voltage in the range 3.6V to 5V

The key thing that this equation shows us is that the output current depends on the log of supply voltage. Thus changes in supply voltage will cause relatively small changes in I_{out}. The circuit will keep I_{out} almost constant for wide range of supply voltages. It also shows the current is inversely proportional to R_2; whereas, although R_1 affects the current, it does so less strongly due to the log relationship.

Simulation

We can simulate the current source to get some idea of how much better it is than just a series resistor when the supply varies. The circuit is Fig.12 is an LTSpice schematic for this purpose. We perform a DC operating point analysis while sweeping the parameterised supply voltage through the range of variation. We will use 3.6 V to 6 V to match our earlier discussion. The simulation also includes a model statement for a diode which approximates a green LED with a forward voltage of about 2.2V at 20mA. The model does not attempt to represent any real device.

Running the simulation produces the results show in Fig.13. Here we see the current in D_2 varies from about 8.5mA to nearly 20mA, which is close to our estimate earlier. The current in D_1, supplied by the current source, only varies by about 1mA over the supply range. The current source reduces the LED brightness variation from about 58% to 5%, which is a significant improvement.

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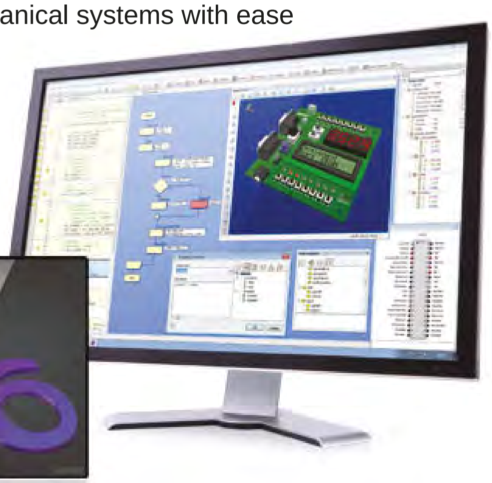

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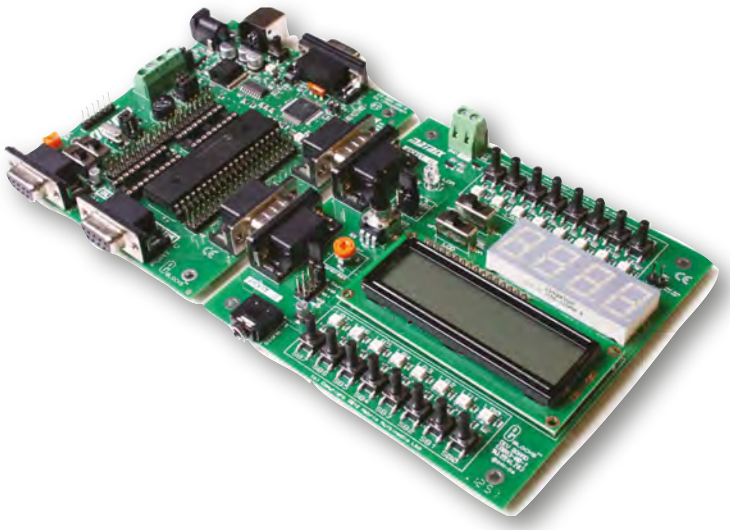

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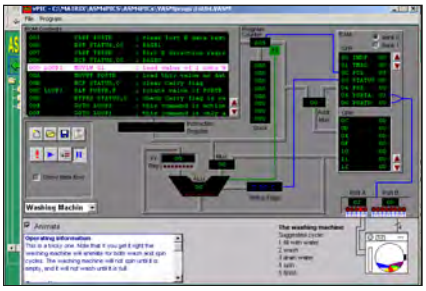

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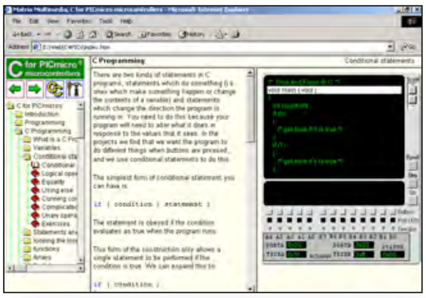

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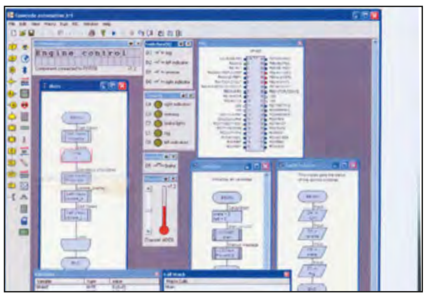

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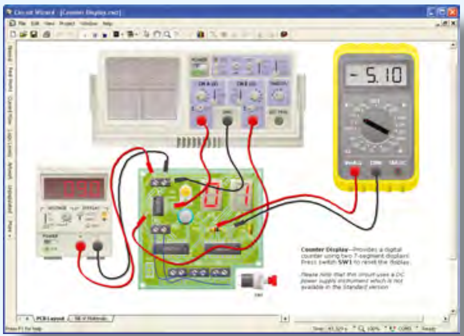

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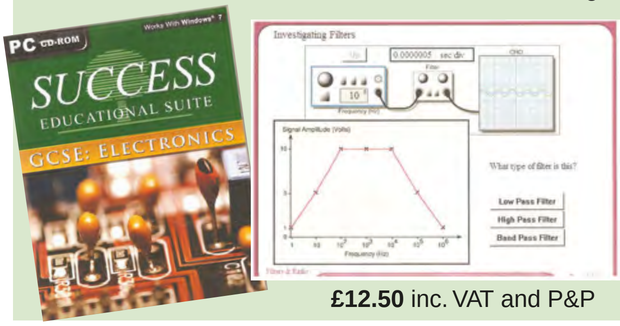

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NET WORK

by Alan Winstanley

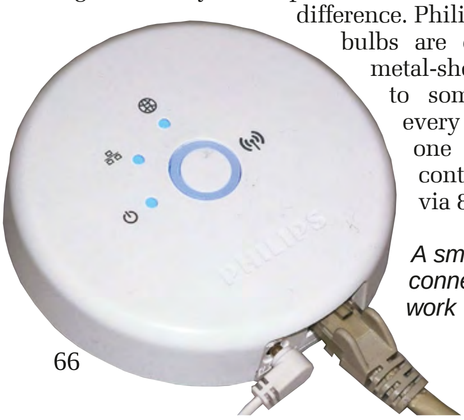
Under the Internet spotlight

LAST month, I described how ordinary kitchen appliances are starting to become network-aware. The forthcoming new Smart Slow Cooker from Crock-Pot, for example, can be controlled over the network and users can receive countdown alarms on a smartphone or tablet. Thanks to the huge strides made in LED technology, the ordinary domestic lightbulb is also undergoing some long overdue rejuvenation as crude old incandescent bulbs finally bite the dust. (As an aside, English physicist Sir Joseph Swan started working on the electric lightbulb in 1850 and patented the design about a year before Edison, in 1878.)

Modern LEDs are generations ahead of the filament bulbs pioneered by Swan over 160 years ago, and new waves of LED lights appear almost annually. Halogen bulbs now enjoy a mainstream lighting role over CFLs, but LED systems offer greater power efficiency and solid-state reliability, at a price. Lamps containing clusters of 3528 (ie 3.5 × 2.8mm) or 5050 surface-mount white LEDs are sold on eBay though the quality and legal compliance can be dubious. Flexible ribbon tapes of LEDs are also available on reels for edge-lighting which are fun to experiment with, and they have basic IR remote controls to change colour or produce a dazzling light-pipe chaser effect.

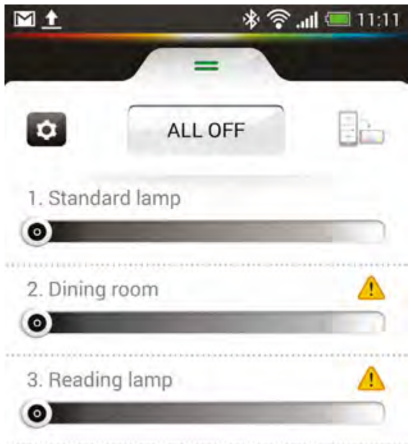
Philips Hue is a personal wireless lighting system controlled by an app

It was only a matter of time before multi-colour LED lightbulbs appeared, and Philips offers the Hue LED bulb, a high efficiency mains-powered ES (screw fitting) bulb with a difference. Philips' mushroom-shaped bulbs are quite compact but a metal-sheathed body alludes to some electronics inside every lamp: for starters, each one has built-in wireless control and is controlled via 802.11 Wi-Fi.



A small wireless bridge connects Hue to the network

A dedicated wireless bridge unit connects to the home network via an Ethernet cable and then each light bulb can be controlled by an app on an Android smartphone or iPhone. Up to 50 bulbs could be controlled where budget allows. Philips loaned a Hue Starter Kit consisting of three such lamps, a bridge and mains adaptor. Each Philips Hue bulb consumes about 8W and has a light output slightly less than a 60W traditional lamp. The colour temperature can be varied from 2,000-6,500K, ie from a warm, yellowy white to ice-cold daylight, but the real trick lies in the Hue's multicolour LED technology, as each lamp can be adjusted to emit almost any colour of the spectrum. Wi-fi is used to bridge the wireless lamps to the home network, and as Philips is a member of the ZigBee Alliance, a ZigBee-based low-power 2.4GHz wireless control system is used. A smartphone or tablet can then set the lighting intensity or colour, or turn them on or off altogether.



The Hue app that controls intensity and colour of each bulb

Setting up a Hue system proved to be extremely simple and I was pleasantly surprised by the near faultless setup routine. First the Hue app can be downloaded by scanning a QR code and then each lamp is screwed in (ES-BC adaptors may be used) and powered on. The Hue wireless bridge is then hooked onto the home network via the Ethernet cable supplied – I used a spare Homeplug port – and then the bridge will power up. A Shuko mains adaptor is best for the Euro-style two-pin power supply, readily available in major hardware stores.

Appy times

Few instructions were needed and the Hue setup routine was intuitive and easy to follow. After installing the app, the phone or tablet searches the network for any available Hue bulbs and then the fun begins! The Hue app consists of 'Scenes', which are colour images from your device's gallery or a camera snapshot, and on-screen icons – one for each lamp – are slid around the touchscreen. The corresponding lamp then changes to approximate the onscreen colour. Some Scenes are very colourful, such as a set of colouring pencils, while others are more restful, eg, an Alpine setting. Various colour palettes are therefore available, or you could photograph something and let the Hue lighting roughly match a chosen colour.

The Pencils Scene showing three icons for each lamp's colour

Individual slider controls set the bulb's intensity, and a single button can turn off all lamps simultaneously. Icons can be dragged and dropped into a larger group icon, allowing multiple lamps to be controlled simultaneously by dragging the group icon around the screen, but this was a little frustrating to organise on a smartphone screen. The lamps can be renamed on-screen to something more recognisable like 'bedroom' or 'lounge' and the bulbs flash when being renamed. An option allows the smartphone to be used to shake the icons to a random new colour. The change of colour was near instantaneous, with very little lag present over the network.

In practice, it was sometimes easier to use the app's basic screen (swipe a tab upwards to reveal it) which displays simple sliders showing the lamp's colour and a dimmer to set the brilliance. Turning the phone through 90° opens a simple colour palette where the lamp's icons can be dragged around to change their colour, and also it was easy to select warm or cool white here. White light presets are already included for relaxation, reading and so on. Multiple spotlights can, of course, use individually-programmable Hue bulbs for mood lighting or highlighting a feature. Scenes are a good way of creating colourway presets.

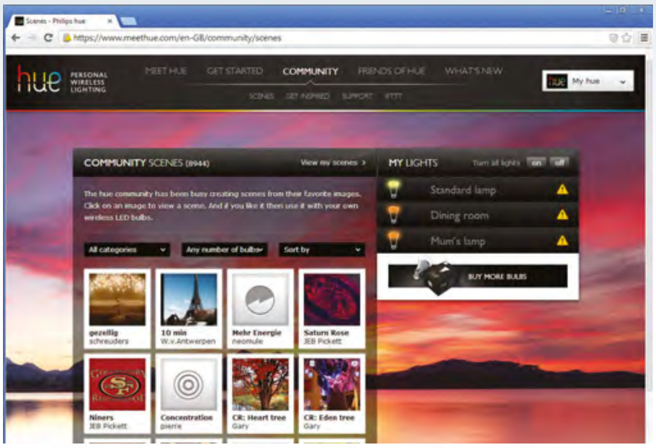
Once or twice I was unsure what colour the bulb actually was, or how it got to be like that to begin with, or even whether it was left on or off, so the basic screen was used to reset the lamp again. A minor leap of faith is needed in order to leave lights permanently switched on 'at the wall' with the app controlling them instead. Practice makes perfect, and the overall usability will improve with experience.

Apart from the psychedelic colour changes, the Hue app has a seven-day alarm to switch a scene on and off at preset times and day(s) of the week. Lighting can be programmed to gently wake you up in the morning or soothe you off to sleep as three-minute or nine-minute fade-in/outs are options in each scene. A countdown timer option can switch scenes after a delay. The app's geofencing (GPS location-aware) feature was not tested.

In its basic mode, the Hue system worked well and it was great fun to remotely-control various room lights while watching TV or having dinner, or dim them to suit the mood. I found that the ability to change the bulb's colour temperature between a warm relaxing glow and cool white was a very beneficial feature, and might help those who suffer from migraine headaches. There is no escaping the fact that everything revolves around the app, and some concerted tapping and swiping is needed to navigate around the system at times, but that's to be expected.

A set of Hue lamps in a spotlight luminaire with each lamp individually programmable over the network

Philips' dedicated website **meethue.com** allows users to set up an account. In the event that your wireless bridge is out of reach (eg, you are away from home) then web-based access allows the bulbs to be turned on or off remotely from anywhere in the world that has net access. Colours and intensity can be changed by selecting a different preset scene



The Philips Hue website provides a basic web-based control system for users' lighting

(no sliders or icons here) and on-screen bulb icons reflect the colour of the bulbs. You could also control the lighting online if your phone or tablet battery has gone flat after a long day.

Hue and me

A quick look around Google Play Store saw me downloading several promising-looking independent Android apps for testing. The *Hue Talk app* uses Google voice recognition to add voice control of Hue lights, but this failed to work in my tests, as did an app called *Speech Hue*. Hopefully this will improve over time as more developers throw their hats into the ring.

Other apps worth checking out include *Speedy Hue*, which claims to be the quickest way to turn a lamp on or off, group them together and a main screen widget lets you flip them with a single switch. Regular readers will recall my item on Near Field Communications tags (*Net Work*, February 2014) and sure enough some Android apps such as *Tag-A-Hue* support NFC, so you could tap a tag to set the lighting. Also from the Play Store, *Hue Fireworks* and Xmas apps will modulate the lighting in sympathy with a seasonal soundtrack, while *LampShade.io* claims to provide quick manual controls and animated displays, with alarms and NFC also available. *Hue Disco* for Android aims to use a device's built-in microphone to provide a sound-to-light experience or strobe and seems to be well regarded. It is not clear what effect treatment like this can have on the bulb's claimed 15,000 hour/25,000 cycles lifecycle though.

Last month I mentioned IFTTT (If This Then That), a web-based service that combines Triggers and Actions to automate some tasks, and IFTTT supports Philips Hue. This means, for example, that the lights can reflect an Internet-based event, eg, turning a lamp pink when a Gmail is received, or if I'm tagged in a Facebook photo, flash a lamp, or light a blue lamp when rain is forecast. You can try writing your own 'Recipes' by visiting **IFTTT.org**.

High-efficiency multicolour wireless LED technology does not come cheap, and the Philips Hue Starter kit with three lamps and wireless bridge costs £179.95, available exclusively from Apple Stores and online. The bulbs cost £49.95 individually. This will be seen as very expensive for mainstream users, but there are many who don't blink at using a £500 smartphone or tablet and there is a clear market for attractive technology products like Philips Hue, especially given the extremely flexible control and enhancements that they offer. Other Hue lighting products are also available and readers can expect many more exciting developments like these in coming years.

That's all for this month's Net Work. You can contact the author at **alan@epemag.demon.co.uk.**

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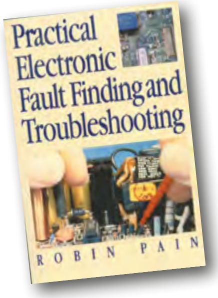

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Content may be subject to change

Mini Audio Mixer

We've published a number of audio mixers, large and small, over the years, but they've all been 'general purpose'. Not that that's a bad idea – it's just that when you need one for a specific purpose, you need a specific purpose mixer! This excellent compact design has minimal controls – just three inputs and *no* knobs – to discourage well-meaning, but incompetent twiddlers!

Cranial Electrical Stimulation Unit

Commercial cranial electrical stimulation (CES) units cost hundreds of pounds, but this one is cheap and easy to build. It is battery-powered, portable and has adjustable current delivery and repetition rate.

Rugged Battery Charger from Bits'n'Pieces – adding meters

When we put together our *Bits'n'pieces battery charger*, we promised to show how to add meters to show both current and voltage. Sure, it's getting out of the realms of a dirt cheap charger, but meters are useful – and still pretty cheap!

Teach-In 2014: Raspberry Pi – Part 9

Next month, our *Pi Project* features the construction of an infra-red lighting source, while *Home Baking* introduces the Pi's NoIR camera. These two projects can provide you with the basis for an excellent night-vision system. *Python Quickstart* will show you how you can write HTML files and render them in a web browser from within your Python code. *Pi World* delves into analogue and digital I/O using the popular, versatile and brilliantly named *Custard Pi 2*.

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